MAB Technical Notes 10

Trends in research and in the application of science and technology for arid zone development

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MAB Technical Notes 10

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Trends in research and in the application of science and technology for arid zone development

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Launched by Unesco in 1970, the intergovernmental Programme on Man and the Biosphere (MAB) aims to develop within the natural and social sciences a basis for the rational use and conservation of the resources of the biosphere and for the improvement of the relationship between man and the environment. To achieve these objectives, the MAB Programme has adopted an integrated ecological approach for its research and training activities, centred around fourteen major international themes and designed for the solution of concrete management problems in the different types of ecosystems.

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Preface

The arid and semi-arid regions of the world cover about one third of the earth's surface. Large parts of these regions became desertified during centuries past; but the process is still continuing, and many vulnerable areas are turning into desert. The problem of desertification has been highlighted in recent years by the disasters of the Sahel and parts of Asia and Latin America. Today, desertification threatens the livelihood of some 50 to 80 million people living in the drier areas of the world.

Current Unesco activities in arid and semi-arid areas are undertaken within the Man and the Biosphere (MAB) Programme and the International Hydrological Programme (IHP). Two of the fourteen major research themes under the MAB Programme deal with the problems of arid zones. Project 3 is concerned with the impact of human activities and land use practices on grazing lands, including those of arid and semi-arid areas, while Project 4 deals with the impact of human activities on the dynamics of arid and semi-arid zones ecosystems, with particular attention to the effects of irrigation. At present, some ninety field research projects are being implemented under MAB Project Areas 3 and 4 in the fields of grazing lands and irrigation respectively. Many of these field projects are also being utilized for *in situ* training for scientists and decision-makers involved in the management of the natural resources of the arid zones. Furthermore, several MAB Technical Notes dealing with such subjects as the problems of the Sahel, obstacles to the development of arid zones and the problem of irrigation have been published.

In 1975, at the request of the United Nations Economic and Social Council (ECOSOC), Unesco convened an *ad hoc* Inter-Agency Task Force which prepared a report identifying the obstacles encountered by developing countries in the development of their arid zones and which had not yet been overcome by science and technology. This report was submitted to the United Nations Committee on Science and Technology for Development (CSTD) which met in April/May 1975, and was subsequently published in a revised and expanded version as MAB Technical Notes 6 entitled 'Development of arid and semi-arid lands: Obstacles and prospects'.

In August 1976, ECOSOC requested the Secretary-General of the United Nations to ensure that the *ad hoc* Inter-Agency Task Force prepare a second report, dealing with proposals to close the gaps in scientific knowledge and technologies concerning desertification. In this connection, the Task Force was to call on the knowledge of experts from all countries which had already acquired experience in dealing with the obstacles to the development of the arid zones, and to take into account the information and recommendations resulting from the United Nations Conference on Desertification. In view of the broad scope of the subjects to be covered by this second report, it was considered appropriate to contract a consultant for the preparation of documents to serve as a basis for a workshop with specialists from different regions of the arid and semi-arid world.

To this end, Unesco engaged as consultant Dr. Randall Baker, Dean of the School of Development Studies, University of East Anglia, England, to prepare a draft document entitled 'Report on Research Trends and Technological Perspectives for the Development of Arid and Semi-Arid Zones'. For the preparation of the draft report, Dr. Baker visited several national institutions, as well as FAO, WHO and WHO, and consulted existing available documentation, including papers utilized in the preparation of the United Nations Conference on Desertification. The document prepared by Dr. Baker was discussed at informal consultations in Nairobi during the period of 25 August to 2 September 1977, on the occasion of the United Nations Conference on Desertification. The

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report, as amended in the light of the comments of the participants and the recommendations of the United Nations Conference on Desertification, was discussed at a meeting of the Inter-Agency Task Force held at Unesco Headquarters in Paris on 11 and 12 October 1977.

A revised version including the comments of the Task Force was submitted to the fourth session of the United Nations Committee on Science and Technology for Development (CSTD) in February 1978. The CSTD welcomed the report and requested that Unesco refer it to its Executive Board and to the Governing Council of the United Nations Environment Programme for consideration. The Committee also requested Unesco to 'continue its work on and to publicize widely the Report of the United Nations Educational, Scientific and Cultural Organization on the work of the *ad hoc* Inter-Agency Task Force (E/C.8/55) and to make it available to national focal points'. In October 1978, the report was submitted to the 105th Session of the Executive Board of Unesco for information and consideration. The Executive Board made several suggestions concerning the contents of the report and recommended publication and widest possible diffusion as a MAB Technical Note.

The present MAB Technical Note is thus based on the document presented to the Executive Board of Unesco and amended in the light of its comments. The main sections deal with:

- a description of the resource base and its potential for the development of the arid and semi-arid zones;
- a review of the general trends and major changes in the nature and organization of research and its application during the critical period of 1950-1975;
- the trends and gaps in research by individual sectors of the economy;
- the planning implications arising from the study.

In view of the wide contemporary interest aroused by the subject matter of this publication, it was decided to include in the bibliography a number of important references not mentioned in the text.

Unesco wishes to thank Dr. Randall Baker, who prepared the draft report which formed the basis of this Technical Note. Thanks are also due to Dr. J. Schechter of the Ben Gurion University of the Negev (Israel) who worked on Part V of the text. The following experts also participated in consultations on this document: M. Anaya (Mexico), A.J. Askew (WMO), G. Aubert (France), O. Ba (Sahel Institute), D. Bargman (WHO), M. Batisse (Unesco), O. Bognounou (Upper Volta), F. di Castri (Unesco), J.K. Cuttaree (Unesco), K. Dettman (Federal Republic of Germany), J.W.K. Duncan (WHO), A.H. Felemban (Saudi Arabia), C.P. Ferreira (Cape Verde), C. Floret (FAO), B. Givoni (Israel), E.R. Hajek (Chile), Khalid Hamad (FAO), M. Kabala (Unesco), M. Kassas (Egypt), M. el Khash (Arab Centre for the Study of Arid Zones Development); K. Lange (USSR), H.N. Le Houérou (International Livestock Centre for Africa), J. Mabbutt (Australia), H.S. Mann (India), P. Olembo (UNEP), P. Pelissier (France), N.K. Pham (UNEP), C.E. Poulton (FAO), R. Reynolds (UNITAR), H. Ruthenberg (Kenya), E.H. Sene (Senegal), A. Smaoui (Tunisia), B. Spooner (Iran), S. Soares (Cape Verde), J. Thomas (USA), G. White (USA), and A. Zeweri (UNIDO).

In view of the importance of the application of science and technology to the rational development of arid and semi-arid zones, this MAB Technical Note is expected to be of direct relevance to those concerned with natural resources research and development in arid zones, as well as to decision-makers, administrators and university students.

Contents

I. Introduction 9

II. Characteristics and potential of arid-zone resources 13

III. Research trends 1950-1975: implications for the arid zones 21

IV. Current trends in research, and the application of science and technology in the arid zones by economic sector. 29

V. Gaps in research and perspectives for the application of future research and training 41

Bibliography 51

I. INTRODUCTION

It is now over 25 years since the Unesco Arid Zone Research programme began, and in that time the volume of research work, as well as the number of institutions for research on arid zones have increased substantially. During this period there has also been unparalleled technological and social change, in particular in the semi-arid zone where 72 per cent of the population living in drier areas is found. An active and expanding research base has produced a continuing flow of scientific and technical advances covering almost every aspect of resource use and development in the arid zones: new forms of irrigation; genetic improvements leading to the development of drought-adapted crops with shorter life cycles and which are sensitive to photoperiodism; new types of energy-collection and conversion systems; desalination and brackish-water treatment and use; new systems of protein culture; new methods of transport such as the hovercraft; etc. There are substantial advances to be recorded in all technical fields, not least of which are the various forms of weather and resource-monitoring systems made possible by the rapid progress in satellite technology, affording mankind an unprecedented opportunity for rapid and regular data collection and correlation on a global scale. For some inhabitants, the application of research has meant greater insulation from the principal hazards and stresses of the arid zone: a more acceptable physiological environment through new systems of heating and cooling of dwelling and work places; controlled closed high-humidity environments for recycling precious water in the cultivation of crops, such as the tented agriculture of Abu Dhabi, and the protection of flocks and herds from epizootics such as Rinderpest by the development of new forms of prophylaxis. The research effort in science and technology has been, and continues to be, impressive.

Unesco (1977b) made the point that, although between 1959 and 1975 there had been substantial technical advances of the types mentioned above, some of the earlier expectations in such fields as large-scale cloud seeding or desalination had not been matched by results. Also, it was noted, the emphasis in research had been on the narrow technical aspects of combatting the physical problems of arid zone development so that in many cases, particularly in rangeland management and irrigation-water management, the application of research results sometimes led to a degrading of the physical resource base. This situation was not due to any inadequacies in the technical research itself, but often to the weakness or absence of necessary research on social, economic and political factors. Far too often scientific research findings have run ahead of the knowledge of cooperant social factors such as available management skills, marketing infrastructure, diet, tenure, customary law, etc. In addition, serious problems were encountered in transferring research findings which were often evolved outside the arid zones from one place to another where the social and economic context was different. This was, for instance, the case with veterinary medicine and water development in nomadic areas of Africa. Here, technologies which were in themselves perfectly adequate, produced destructive consequences when applied to cattle systems based on the conservation of livestock numbers *in situ* by a human population often growing at over 2 per cent per annum.

In part as a consequence of the experience of recent years, it has become increasingly common, for instance at international conferences, to hear the cry: 'We do not need any more research; we cannot apply more than a fraction of the research we have'. What should be said is that there is still a most definite need for research in some neglected, technical areas, but more particularly in integrating the social and economic factors as they occur in a

local situation. Without this integration, the results of existing technical research cannot be applied with less than the present high risk of failure. This is particularly true for the developing countries where innovation has to be accommodated within different long-established but rapidly changing cultural, social and economic frameworks. It is indeed one of the main intentions of this Technical Note to point out the dangers of yielding to cries of 'no more research'; it is reorientation and consolidation which is essential to enable existing and future technical research to become more appropriate and applicable at the local level. Partly for this reason, within most United Nations agencies, there is now a shift of emphasis towards evaluating existing experience and identifying gaps in earlier research, so that better use may be made of skills and investment in the future.

In addition, it is clear from the experience of the last generation that the application of research in many developing countries in the arid zones, to be more successful, needs to include systematic monitoring and evaluation. The fact that this has rarely been done is one reason for the frequent repetition of errors.

For these reasons, this Technical Note concentrates on the organization and structure of research rather than on listing individual advances in technology. These advances are described in two other recent publications (UNITAR 1977; United Nations 1977). By taking this approach, it is hoped that it will have a wider relevance than is customary for papers on research and technology, in that it would be of value to a range of decision-making, funding and planning bodies at the national and international level, particularly in developing countries. In addition, it will become clear that, for each of the main economic sectors identified in Part IV, there is a need for serious, detailed evaluation of the sort made at a more general level in this Note.

A positive stance has been adopted in order for this Technical Note to take the debate forward from Unesco (1977b). After this introductory section, Part II looks at the resource base and the potential it affords for development of the arid and semi-arid zones.

Part III reviews the general trends and major changes in the nature and organization of research and its application during the period 1950-1975 which was an era of serious and accelerating mismanagement of the arid zones.

Part IV examines the trends and gaps in research, by individual sectors of the economy such as primary production,[1] industrialization, urban development, recreation and tourism. It was thought more useful to make the evaluation on this type of sectoral basis than on, for instance, a resource basis such as energy, water, etc., for this is most often the way responsibilities are divided in government and, consequently, this is most often the way that problems are perceived and acted upon by decision-makers and planners.

The final section, Part V, considers the planning implications, predominantly at the national level, which arise from the previous discussions, including identifiable gaps needing priority attention and the relationship between research, technology, policy and the planning machinery. For over 30 years, much has been said about the need for integration so that, for instance, ecological problems based on an energy balance concept, can be tackled in a way which allows all the components of an energy flow system to be considered and directly incorporated. Why, one may ask, has the request for integration continued so long without abating? The answer is not usually the lack of research methodology to cope with the intellectual requirements of the problem. More often the inadequacy lies in the fragmentation of research, administration and decision-making as it is usually organized at the national, international or agency level. This difficulty has been recognized often enough, but in order to find remedy which produces real and effective integration, very positive suggestions have to be made about the administrative reorganization of research and its relationship to planning and to the process of change at several levels.

One objective of this Technical Note is to give some concrete form to vague expressions such as 'integration'. It is an inescapable conclusion of any evaluation of this sort that there is a considerable gulf between the way physical and social scientists have reorganized their efforts into a more problem-oriented framework, and the structure of most governments, places of learning and some international agencies. So much more could be done to overcome many of the obstacles to development in the arid zones if only the same effort, skills and funds which are devoted at present, were incorporated within new, linked research and implementation frameworks.

1. In this Technical Note, 'primary production' is used in the economic rather than agricultural sense, to include agriculture, livestock and mining.

Throughout this Technical Note, the terminology used is that of the Unesco map of the World Distribution of Arid Zones (Unesco 1977c) so that, as in the report on obstacles to development (Unesco 1977b), the boundary between 'arid' and 'semi-arid' may be considered roughly as the division between areas where rainfed farming is not a viable proposition in most years and areas where a population, even with the risk of periodic serious drought, has been able to sustain itself on rainfed agriculture over a substantial period of time. This distinction is more useful than taking actual rainfall limits, for the significance of these criteria varies considerably with latitude as, for instance, between the winter and summer rainfall semi-arid zones of Africa north and south of the Sahara. Two further remarks should be made at this stage.

Firstly, the area under rainfed agriculture has undoubtedly expanded in this century (e.g. in the 1950's in Niger) but experience suggests that the expansion was often into areas not suited to long-term production (for instance north of the 400 mm line in Niger and south of this line in northern Africa). The semi-arid boundary, according to the above definition is not necessarily, therefore, the boundary of existing cultivation at the present time, especially in the conditions of the period 1945-1977, but of reliable rainfed cropping over a long period. Part of the 'desertification' process at present under review, is a readjustment of population distribution and land use back to the semi-arid boundary, following the conclusion of a brief, more humid phase.

Secondly, semi-arid areas vary enormously in physical terms, grading into savanna cultivation at the humid margin and livestock nomadism along the drier edge. In addition, the physical and socio-economic conditions of countries in the same physical zone also vary, so that large areas of Mali and Australia, for instance, are in the same aridity category according to the Unesco map. One country has a large, indigenous population with a variety of established land use methods and social customs requiring research and through which research findings have to a greater or lesser extent to be channelled. The other builds on an almost clean slate from the socio-economic point of view, with high technology, commercialization, research institutions, modern management and an already well-developed infrastructure. In addition, Mali has no coastline, and a glance at any map of the arid zones will illustrate very dramatically the gravitation of urban tourist and industrial development to the coast where this is possible. Other elements of diversity include mineral wealth (compare Saudi Arabia and Jordan); the extent of arid area in relation to size and resources of other physical regions (Kenya and Democratic Yemen); topography (Peru and Chad) and the proximity to alternative employment prospects (Yemen and Democratic Yemen). Clearly, any broad physical division of arid areas based primarily on climatic factors conceals a very wide range of diversity highlighting not only the potential dangers of indiscriminate technology transfer but also the need for research on the local conditions within which change is to be effected.

II. CHARACTERISTICS AND POTENTIAL OF ARID ZONE RESOURCES

The area of the four main zones (hyper-arid, arid, semi-arid and sub-humid) of the Unesco map (Unesco 1978) accounts for approximately one-third of the land surface of the globe and contains approximately 14 per cent of the world population, almost three-quarters of which is concentrated in the belt classified by Unesco as 'semi-arid'. In considering the arid zones, it is, however, essential to bear in mind the complementarities and interrelationships between the arid areas and the more humid fringes with which they are usually intimately connected. This is best exemplified in Chile and Peru, where the arid zones are backed by high mountain ranges, giving a wide range of natural environments over a short horizontal distance. During this century, the arid zones have represented the last great frontier into which people have expanded before the pressures of rapid population growth. However, in contrast to the negative aspects of 'desertification' receiving so much attention at the present time, it should be remembered that research and exploration have revealed a wealth of actual and potential resources in these often physically deteriorating regions. In particular, the discovery of minerals such as oil (Arabia and northern Africa), uranium (Niger), copper (Botswana), iron (Mauritania) and phosphate (Morocco) has generated funds which some countries (e.g. Saudi Arabia, Libya) have coupled with national policy of diversifying an often narrow economic base. Consequently, very substantial funds have become available internally (Iran, Algeria, etc.) or by way of south-south gifts and loans (Saudi Arabia to Sudan, Libya to Niger) for the development of the arid zones.

To a large extent this positive approach towards realizing the resources of the arid zones stems from a desire to maintain growth after mineral resources are depleted by implementing a programme of diversification now. In addition, since 1973 many developing countries in the arid zones have become very much aware of their dependence on food imported predominantly from the developed world, some of which has tripled in price during this period. As a result, there has been a major shift of investment towards expanding and intensifying the food production capacity of some non-oil producing countries in the arid zones (e.g. Sudan). Furthermore, the financial capacity now exists for extremely rapid transformation in the arid zones, as technology may now be introduced on an unprecedented scale. Expectations are often pitched at a very high level based on a 'transformation' approach using large-scale capital injections and high technology, especially where lands are considered under-populated. Sudan, for instance, could become a major food exporter in the next decade or so, with financial aid from Kuwait and Saudi Arabia.

Although the recent transfer of funds to certain oil-producing areas of the arid zones has brought with it the potential for major investment programmes and transformation of the means of production, it also carries with it a potential threat. The record of earlier attempts to bring about dramatic change in the arid zones contains examples of serious environmental mismanagement on a vast scale: the Groundnut Scheme in former Tanganyika, the Dust Bowl of the United States and the Virgin Lands Schemes in Kazakhstan, USSR. There is always the danger that development which is supported by vast capital resources and which seeks to bring about the greatest change in the shortest time, often for political reasons, sacrifices adequate research on the grounds that the latest technology can be bought *en masse* making it possible to achieve results in the shortest time possible.

PEOPLE

The people of the arid zones are not just a resource or a potential resource. They are the justification for all other research. In the past the arid zones have been the cradles of great civilizations and religions; but their role has diminished and they are now very often peripheral to national economies and a source of unskilled migrants. One of the greatest areas of untapped potential in the arid zones is the people, who remain amongst the most isolated from modern education and other social facilities and who suffer increasingly from malnutrition and man-induced diseases. Yet these people are the repository of a considerable legacy of detailed environmental knowledge and great unwritten cultures which have been to a large extent disregarded in this century during the colonial era and the subsequent drive to 'modernity'. The reason such people have survived for so long against such odds is because they have a profound understanding of their own environment within the constraints of their own technological horizons. This, however, did not equip them adequately to cope with the intense pressures and the rapid pace of change in the present century, when their old individual practices became collectively destructive under population pressure. Too often they and their practices were dismissed as 'primitive' and blamed for causing the current deterioration. There was almost no development of a two-way research programme to give an understanding of the rationale of these traditional land use methods and survival strategies, which like those of the Nabateans might once again prove economically and ecologically attractive.

The desert environment imposes high thermal stresses on the inhabitants. In summer the high ambient air temperature, coupled with high intensity of solar radiation, results in appreciable heat stress, both outdoors and indoors. In winter many desert regions are cold and windy. Traditionally, populations have evolved physically and have developed dwellings and life styles which, within technical limits, minimize the discomfort of the arid environment (e.g. the water-cooled houses of the Syrian desert or the tent of the Bedouin). However, it is frequently the case that the arid zone climate is presented in a negative light as a basis for human habitation. It should be emphasized instead that it is free of smog and pollution, the air is clear and the climate in areas away from the coasts is often extremely agreeable; hence the rapid development of new towns, often for retired people, in many parts of Arizona and New Mexico.

In addition, when substantial numbers of people move out of the arid zones it is not inevitably because they are fleeing an inhospitable physical environment. Instead, they may be leaving an area of overpopulation and a lack of employment opportunities as well as a situation of very low access to modern social amenities and services. It is in the arid zones that the greatest problems occur in the provision of services for several reasons: the population practising the traditional way of life is often isolated, thinly spread and mobile; the arid zones, in their peripheral context, are the areas least attractive to the new class of professional people, often urban-bred and educated, which provides the services; and the arid zones too often have a low priority in government economic and social planning as they have very little political influence at the centre, in contrast to their sometimes dominant position in the political order of the earlier years (e.g. the Fulani Empire in western Africa). Frequently the colonial era reversed an earlier power structure in which the mobile nomad held sway over the settled cultivator who was more vulnerable. The result of this situation is that the population of some parts of the arid zones in developing countries, less educated and untrained in the formal sense, migrates in the face of seemingly hopeless and diminishing prospects to the towns and to what turns out very often to be equally hopeless prospects. Older crafts and skills such as metalworking have disappeared with the advance of cheap imports or urban manufacturers. In Australia, the low capital requirements needed to start up in the arid areas have incited the flow into these regions as a 'refuge' of the poorer part of the population.

ENERGY

The energy inflow from the sun into the arid zones is very high, rising to an average of 275 watts per square metre. Although the angle of incidence of the sun's rays at this point on the earth's surface is not as high as at points nearer the equator, more energy penetrates to the ground surface. This is mainly a result of the clear skies and the transparency of the atmosphere accompanying the anticyclonic conditions which prevail for all, or most, of the year. Since agriculture

may be defined as the channelling of available energy through a preselected plant/animal biomass, the potential for the production of food is, from the energy point of view, very high indeed. The present flaw in this equation is, of course, water availability; for those same clear blue skies fail to produce more than a limited, and often intensely seasonal, amount of precipitation, the great majority of which is lost by evaporation and runoff. Where water and arid zone energy can be applied in optimal proportions, there is often extraordinary productivity. In parts of the Wadi Fatima at Bahra near Jiddah, reliable groundwater is capable of producing eleven cuttings of bersim (*Trifolium*) per annum. In Tunisia, yields of 25-30,000 kg of dry matter per ha/yr of fodder crops have been obtained. The effective use of the high solar energy input for agriculture is being increasingly realized at the moment by: the more effective collection and storage of water (e.g. water harvesting techniques and aquifer recharge); the adaptation of crops and animals where appropriate to the peculiarities of water availability by genetic improvement; the modification of the microclimate through mulching, tents, etc.; and the introduction of water from an expanding range of exotic sources or groundwater supplies.

The climatic features of deserts (the high intensity of daytime solar radiation and of nocturnal outgoing longwave radiation, the low humidity and the large diurnal temperature amplitude) enable substantial reductions to be made in the energy needs for thermal comfort by means of appropriate building design and choice of materials. In addition, it is possible to develop low-cost, simple-technology systems for utilizing solar energy for winter heating and hot water supply and for utilizing night radiation for summer cooling.

At the macro-scale, it would appear that the developing countries in the arid zones will continue to be divided in energy terms into:

- fossil-energy surplus countries (Saudi Arabia, Libya, etc.), which can subsidize their development by the application of cheap energy sources; produce cheap conventional energy by-products such as fertilizer, electricity and gas for their own advancement; and invest the profits of their energy sales into a more diversified development of their arid zones; and
- fossil-energy deficit countries which will continue to be dependent on energy exporters; lose much of their potential investment budget on energy purchases; need to concentrate on energy conservation and, where appropriate, the application of appropriate alternative energy technologies.

There are, however, important areas where research is producing possible solutions to local energy problems such as the domestic fuel crisis. For centuries, villagers, nomads and townspeople have depended on firewood. Recent estimates suggest that two million hectares of woody steppes are devegetated each year and the zone of stripping now often extends for 50 km around settlements. In addition, fuel bills form one-third of family expenditure in parts of upland Yemen and in Sahelian countries. In other areas, such as southern Asia, dung is used as a domestic fuel depriving the lands of a valuable source of organic nutrient and of a potentially considerable reserve of fertilizer if the domestic energy requirements can be met from other sources. Both the social and ecological consequences of this exponential rise in fuel-gathering could be substantially offset by solar cooking and, possibly, heat storage devices and the prospect of methane generation (biogas) from human, agricultural and animal wastes resulting in a by-product which is still valuable as a fertilizer.

It is clear that, although a number of countries are going ahead with solar power stations, there is unlikely to be a very fundamental change in the production pattern of energy in the near future through heat exchange mechanisms, for solar power, particularly in the poorest parts of the arid zones. New systems of energy conversion are reviewed in Part IV. The priority for the present and immediate future remains the conservation and management of conventional energy supplies, but possibilities for alternative local energy resources have been identified based on biogas, strong thermal winds, geothermal energy and the use of reverse electrodyalisis in areas of salt concentrations. With the availability of extensive gas deposits, it has been possible for the USSR to build the largest state electric power station at Mariyskaya in Central Asia.

WATER

Although great quantities of energy are potentially available in the arid zones, the selective rechannelling of this energy into plant or animal food has been constrained by the shortage of water which, after all, is the defining characteristic of these zones. However, despite the relatively small annual precipitation totals recorded, there is still

a considerable loss of water through evaporation, seepage to untapped aquifers and through uncontrolled runoff. There remains considerable potential for the development and better management of water resources (Unesco 1978).

As a rule, the main source of water is rainfall, but the use of annual average figures of rainfall conceals as much as it reveals about water resources. As the average figures decline, moving from the sub-humid through the semi-arid towards the desert, so in general the coefficient of variability of the rainfall rises and the seasonality of rainfall is accentuated. Rainfed agriculture and pastoralism represent meticulous adjustments to the risks associated with changes in water availability over time and space, but even so in many areas over three-quarters of the rain which falls is lost to the atmosphere under intense evaporative sunlight. More of this water will undoubtedly be cycled into production in the future.

In addition to water made available directly from precipitation, exploration has revealed large groundwater reserves. Societies living in the arid zones traditionally supplemented rainwater with water drawn from shallow wells, transported over large distances by *quanawat* (subterranean channels) or stored in lined cisterns. Modern technology permits the exploration and exploitation of deep aquifers such as those discovered in the sandstone of the northern Arabian peninsula, the Nubian sandstone west of the Nile valley and the reserves which lie beneath the Sahara. Here the problem is that, in view of the extremely low rate of recharge of the reserves, they are practically not being locally recharged and if they are not they must be treated as any other fossil fuel. The size of some of the deposits now being tapped is often extremely large, such as the estimated 60 billion[1] m^3 of rechargeable water surveyed beneath the Sahelian zone.

Other sources of water include major exotic rivers which, like the Nile, Niger, Tigris and Colorado, flow through dry regions and have formed the basis for the earliest fabric of statehood and civilization. In recent years, man has extended the natural system of exotic sources with canals and carriers such as those in India, Israel, Syria and the Karakum area of the USSR. The Karakum Canal involved the creation of an artificial river over 900 km long with a completely controlled water regime. In the temperature inversion conditions of the South American Pacific coast, fog and mist, resulting from the passage of warm air over cold ocean currents, create an extraordinary environment in which tree growth takes place with less than 100 mm of recorded rainfall.

A recent conference in California (Sacramento, 31 May-10 June 1977) drew attention to the 'vast amounts' of saline underground water in geopressured and geothermal zones which underlie at great depth many arid areas (e.g. Peru, northern Africa, Australia and Pakistan). These reservoirs, often under intense conditions of heat and pressure, may possibly have sufficient heat and energy to effect self-desalination as they emerge, but this, at the moment, is in the realm of hypothesis only.

Finally, in a short review of water resources in the arid zones, reference should be made to the idea, still to be economically and technically proven, of transporting fresh water in the form of icebergs from Antarctica to the arid areas.

It is evident from air photographs and historical accounts that many areas now almost deserted or the domain of nomads, were once used intensively by cultivators. In this context areas which at one time enjoyed greatly different pluvial regimes are excluded. Of interest are areas in which the pattern of land use has changed for reasons other than climatic ones. In these areas, such as for instance the southern Hejaz, highly efficient systems of runoff management and associated aquifer recharge and cistern storage were widespread. In the Negev it was common to enhance runoff and concentrate water at central points for cultivation using channels. Similar structures may be found in northern Africa, Tanzania and many other locations. Almost universally these 'water-harvesting' structures represented highly efficient methods of utilizing scarce water resources which would otherwise have been lost as runoff and evaporation. These systems have received very little serious attention although they have been used successfully in southeastern Iran and northern Africa for 2,000 years. However, results of experiments with water harvesting in northern Africa suggest that caution should be taken. In Tunisia, for example, a high rate of failure resulted from silting, erosion and high labour requirements. In the Hejaz, traditional societies evolved systems of totally integrated wadi management which used and re-used water at each point along the thalweg of the wadi by technologies appropriate to the gradient and water force at that point; this approach has now been integrated into the Mexican watershed planning concept. Unfortunately, so much research and

1. In this Technical Note, the term "billion" is used to indicate 1×10^9.

development in water management has been conducted in the developed world and transferred to the developing world that this field of runoff harvesting and simple aquifer recharge techniques has been too often bypassed in favour of surface storage structures more suitable in temperate climates. It is an inescapable conclusion of the experience of water development in the arid zones that groundwater represents the most attractive potential resource, as it is available when wanted, it is stored away from the demands of evaporation and will nearly always give a better return on investment than surface storage. Even now, however, so long after the work of the Unesco International Hydrological Decade, groundwater resources are still not properly exploited and much fundamental work remains to be done.

Many parts of the arid zones have supplies of brackish groundwater (up to 6,000 ppm) and in northern Africa and the Middle East forms of salt-tolerant agriculture and livestock have long been adapted to this situation. In some cases, saline water had been used directly for crop production. It now seems that brackish water has a range of production possibilities including protein cultivation in tanks.

The largest water resource potentially available to many countries in the arid zones in the sea. As yet, and it seems likely that this condition will continue into the foreseeable future, desalination for all but certain urban, industrial and tourist purposes seems unlikely to be economical, especially in view of greatly increased fuel costs since 1973. Small-scale solar distillation is feasible and is used to provide for mining towns in Australia as well as for small settlements in the Mediterranean and Caribbean regions. However, here too there appears to be little prospect of any agricultural use of solar-desalinated water, though it may well relieve the problems of small new communities in the arid zone near saline or brackish water. Attempts have been made to utilize saline water as a basis for the economical life as well as social comforts for small communities by harnessing the surplus heat produced in the generation of electricity and using it to desalinate water for domestic purposes and for recycled use in high humidity, tented agriculture. These power-water-food complexes exist in Sonora and Abu Dhabi, though, as yet, the cost of the food produced is very high. However, it may be competitive in isolated, barren, wealthy territories such as are found in parts of the United Arab Emirates. The attraction of the scheme is that it utilizes a form of energy which is available wherever electric power is produced and would, otherwise, be lost.

There has long been interest in rainfall enhancement, but it is only in northern Israel, which is situated in the cyclonic conditions of a Mediterranean climate and not the anticyclonic conditions of many dry areas, that it is operational on a regular basis. There it is claimed to yield an estimated 15 per cent average increase in water available through precipitation. However, before the process can be applied, moisture (clouds) must be available in the first instance. A long period of statistical testing is required to establish whether the observed results are simply 'noise' in the overall pattern or whether they represent a positive response to the application of the cloud seeding techniques. Research concentrates on two main aspects of the rainfall-enhancement technology: inducing precipitation to bring rain to areas where otherwise the clouds might pass without releasing moisture; and prolonging precipitation. However, it would appear unduly optimistic to imagine that the results from northern Israel could easily be transferred, in view of the special topographic and climatic conditions at that location. After 1973, attempts were made to try cloud seeding techniques in the Sahel where some specialists suggest there is a problem, not of absence of moisture, but of inducing the 'triggering' of the condensation process. Without a scientifically-organized research programme, it is impossible to state what effect these expensive techniques would have (or have) in the monsoonal conditions of the Sahel or the northern India-Pakistan-Bangladesh area. However, an ability to influence the onset of the monsoon would clearly have an impact on the agriculture of these regions which is as sensitive to the timing of rainfall as to the total precipitation. At the present time, it is impossible to ascertain whether or not this would ever be more than a minor involvement in local storms. Caution is thus advised.

SOILS, VEGETATION AND ANIMAL LIFE

In essence, most soils of the dry areas are extremely fragile and face greater risk of destruction and loss than their counterparts in more humid regions. Once the balance is disrupted, loss of soil in the arid zones is due to the action of wind and rain. Once lost, the soil is slow to regenerate. It is characteristic of semi-arid soils that their biological activity is to be found predominantly in a very shallow horizon near the surface in which the activity is concentrated, usually for very short periods during the rainy season. In some remarkable cases, the physical conditions favouring soil formation have been created

by the activity of man, such as on the terrace systems of northern Yemen, the anti-Atlas of southern Morocco, or in the ancient basins in the Egyptian desert into which the Nile floods have been diverted for centuries. The capital investment represented by these considerable engineering efforts over the millenia is inestimable, but many soils, at present sustained on terraces, are threatened with total destruction as people move away from these often remote areas and the terraces collapse. This is clearly identifiable in parts of the southern Hejaz (Saudi Arabia) and the Yemen at present.

In a wider perspective, semi-arid soils are being lost on a serious scale from parts of the Sahel and northeastern Brazil as a consequence of the expansion of population beyond the safe margins of cultivation, inappropriate cultivation and over-use of the land. In parts of the Sahel, for instance, much of the 'A' horizon has been lost through aeolian erosion with the advance of grain cultivation, and gullying has rent the land. Recent research into dust clouds over the Atlantic using satellite imagery has highlighted the scale of this movement, sometimes representing each year one-third to one-half of the suspended load of the Nile. Weapons also destroy parts of certain of the structural components of ecosystems, e.g. soil. Such damage puts a strain within the ecosystem as its functional processes adjust to imbalance imposed by the original damage. The inherent fragility of the ecosystems of arid zones renders them particularly vulnerable to such strains. Following the Second World War, the effects of military operations on the ecosystems in arid zones have been observed in several countries, e.g. Libya.

The soils of the arid zones are often cited as being deficient in the minerals which could sharply increase their productivity. Although this may be true as monoculture expands and as the demands for increased productivity rise, very often the soils of the arid zones are fertile and very productive if water is available. Certainly it has been the experience in most areas that they respond very positively to effective management. There are also large reserves of phosphates in Morocco and Saudi Arabia, whilst the oil-producing countries are producing increasing quantities of oil-based fertilizer such as urea. Artificial fertilizers are, however, rarely used by the small farmer due to cost, unavailability or lack of the cooperant investment necessary, e.g. in water supply systems, to make the fertilizer really effective. In many areas there has for centuries been a symbiosis between the pastoralists and the cultivators who allow animals to graze their stubble fields in the early dry season, an arrangement which ensured a supply of organic nutrient to the land. Thus, the quality of the soil is maintained by the interlocking of two production systems and the associated social relationship. This relationship is breaking down in, for instance, the Sahel, where competition for land, especially rainfed and newly-irrigated lands as in Senegal, is bringing the two societies into conflict. Consequently, both forms of land use suffer.

In the arid zones, about 18 million km^2 are used for rough grazing to support large herds and flocks. The potential capital value of these animals and rangelands in the developing countries is seen as very considerable in commercial terms, but the marketed offtake remains less than one-fifth of the equivalent in monetarized arid zone livestock economies in the developed world. The by-products (e.g. pharmaceuticals) are barely used at all. In addition, animal supply in developing countries tends to be related to factors of weather (i.e. supply) rather than demand; the quality of the animals is frequently poor, as they are often diseased and infested with parasites from impure water; the stock losses are very high; and the productivity is very low. In addition, the prices for stock are artificially low compared to grain in energy-exchange terms. The very low level of commercial offtake in the developing countries is related to the fact that most animals are retained by the producers as part of their subsistence base dependent on recurrent products (milk, blood, cheese) whereas the market requires commercial production of terminal products such as beef. The rangelands represent a major prospect for extensive protein production either from domesticated, or managed wild ungulates. As with the soil resources, however, at the present time the future potential is being severely jeopardized by serious over-use of the land and a continuing imbalance in the ecological energy equation. In many parts of Africa, the productivity of the rangelands could be more than doubled by controlling stock and human numbers and by revising the system of controlled grazing. There has been a tendency to concentrate efforts as regards the livestock itself, on the introduction of exotic blood. There has been surprisingly little serious examination of the potential of local animals, which often have, for instance, a better tolerance of heat.

In the drier parts of the arid zones, the natural vegetation, or some subclimax form of it, usually provides the basis for human habitation through grazing and browse for herds

and flocks. Towards the more humid margins of the arid zones, natural vegetation or fire subclimax grasslands are replaced by crops as the provider of the subsistence base. Although very few plants naturally occurring in the dry regions have been commercially exploited, this is no measure of their overall value to man through their many functions. The vegetation may act as windbreak, a source of famine reserve, a repository of traditional medicines, catchment protection, a niche for wild animals, an element to bind together the friable soil, a shelter from driving, eroding rain, a source of fuel, a building material, etc. At the same time, the hold of vegetation on the land in the arid areas is very precarious, and whole communities can be eliminated from a region by relatively small absolute increases in human or livestock numbers. Once the vegetation community is disturbed by fuel-gathering, overgrazing or farming practices, a series of events may be initiated leading to erosion and irreversible loss of soil resources. In other cases, the vegetation is maintained at the level of a man-induced subclimax such as savanna grasslands produced by annual burning practices. Here the modification of cultural practices may lead to dramatic changes in vegetation, as was the case with the advance of bush and tsetse after the cessation of burning in parts of Africa. The vegetation of the arid zones has been one of the principal victims of population and stock pressure; perennials have yielded to annuals, annuals to succulents, and succulents to gullies and ravines. In areas of steep slopes, friable soils and intense showers, such as the Baringo area of northern Kenya, the problem has been greatest.

Although much attention has concentrated on the loss of grasslands, in many areas the destruction of woody vegetation for fuel has been equally serious, encouraging higher wind speeds and increased erosion and destruction of cultivated land, particularly around settlements.

Vegetation as a resource in the arid zones must be viewed, then, in a multi-purpose way. Such a perspective may well influence the economic appraisal of its value. Very often it is necessary to consider most carefully the costs of not conserving or not developing the most appropriate form of vegetation in terms of future land and production lost by erosion, destruction of catchment, etc.; when evaluating planning options it is not adequate to make a choice simply on the sale value of the vegetation protected or planted.

Though only a few species are commercially exploited at present (e.g. arabic gum), the potential exists for the exploitation of oil (*jojoba: Simmondsia chinesis*), rubber (*guayule: Parthenium argentatum*) and food (cacti, buffalo gourd, *teparies* and tubrous perennials). Agave in Mexico is a source of fibre, alcohol, flour and nectar. Despite the fact that the natural vegetation reveals a multitude of physical adaptations to the arid zone environment, there has been relatively little systematic study of the commercial value of indigenous vegetation. Instead there has been a preoccupation with certain leading cash crops.

Despite the seeming barren nature of many arid areas, even deserts support a surprisingly large and diverse animal population. This is achieved through extremes of physical adaptation and specialized adjustment to narrow ecological niches. Thus, the natural fauna of any specific locality is highly sensitive to human activity which affects even minor adjustments to the natural environment.

In the past, the animals of the arid zones formed the basis of many parts of traditional economies in addition to the simple provision of food. They yielded hides, skins and hair which were used for clothing and dwellings; they provided the transport for the caravan trade and a medium of exchange. They also provided the raw material for the renowned carpet manufacture of nomadic communities, especially in Turkey, Afghanistan and Iran. In many areas these skills are being lost. In Soviet Central Asia, however, the traditional woolen industry has been developed on a large agro-industrial scale for the production of carpets and cloth.

The exploitation of the natural fauna has, nevertheless, been slight and in general it has given way to the advance of domesticated stock from quite different environments, stock herded by man. Occasionally a pastoral community turns to hunting as a supplement to the diet, especially in times of hardship. Only in the case of bushmen or aborigines is hunting a major element in the diet.

Together, the domesticated stock and the wild ungulate population are able to make better use of the range of graze and browse available. However, as the game animals and larger wild ungulates are not domesticated, control and offtake raise serious problems which have yet to be resolved. In addition, individual species of gazelle, oryx and adax are able to derive most of their water intake from moisture as dew or in the vegetation.

RECREATION

For the dweller in the developed world's urbanized society, the arid zones have several significant attractions:

1. there is a sense of space, clarity, cleanliness and grandeur to which urban dwellers,

paradoxically, seem to respond in a very positive way. In the United States, this has found expression in the 'wilderness' concept and the preservation of vast tracts of 'unspoiled nature' which, owing to isolation and a very slight population density, the arid zones can offer in abundance. Mass tourism would, of course, eliminate this asset;

2. the arid zones are often the repositories of traditional cultures such as the Masai or the Dogon, the Khirgiz, Indian or the Bedouin, which have survived more completely, as a result of isolation, than their counterparts in the humid tropics. However, this aspect of the national culture is the one which many developing countries in the arid zones seem least anxious to preserve or advertise. It is unlikely that these traditional cultures will remain intact much longer in view of intense political, social and economic pressures, unless there is a deliberate effort for preservation;
3. often the arid zones preserve more perfectly than their humid counterparts the archaeological remnants of past civilizations such as Palmyra or Persepolis;
4. the certainty of good weather, coupled with a sense of the exotic, is an irresistible lure for western urban man and this has had a dramatic impact on arid zone countries located closest to the developed world, e.g. Tunisia, Morocco, Mexico;
5. the fauna and flora which have been preserved in some parts of the arid zones such as Tanzania or the parks of Mexico are another attraction. This resource is, however, under intense pressure at the present time with the growth of population on the land increasing, so that politicians in some countries question the wisdom of keeping these reserves for 'wealthy foreigners' at the expense of 'poor farmers or herders'.

Recent research into the tourist development of the arid zones, for instance Tunisia in the 1960's, has revealed that a great part of the profits which might be used for developing the zonal resources are repatriated or accumulated as private lands outside the arid zones. Another study in Saudi Arabia showed that a second home development in the cool mountains was actually taking place at the expense of agricultural land built up over the centuries.

There is no doubt that silence, clear air, space and the associated cultural assets of the arid zones will prove an ever greater attraction as the mobility of urban man and the pressures of the urban environment are accentuated.

MINERALS

In the arid zones, prospecting for minerals is always easier than in the more humid areas where the geology is clothed in vegetation. Prospecting by remote sensing using a variety of parameters has accelerated the process of investigation, and the decade of the 1960's saw very considerable advances in the opening up of new reserves of uranium, oil and phosphates. Apart from the non-zonal minerals such as oil, there are many deposits which are directly or indirectly the product of the arid environment. Examples of these environmentally-related minerals deposits are: the nitrates and the guano of the Atacama and the extensive reserves of halites which have long formed a medium of exchange between the desert and the sown.

Several arid zone countries now subsist very largely on one or two major mineral resources: oil, copper, phosphates or uranium. This has led to the establishment of new settlements in the desert (Dharan, Das Island, Arlit) in which the highest standard of a western life-style has been created with almost no thought of cost, but offering only little direct employment to the local population. On the other hand, the very considerable wealth generated offers a means by which potentially rapid transformation of the arid zones might take place. This wealth, since it does not accrue to the bulk of the population, as for instance with agriculture, leaves the governments of these mineral-rich countries in the unusual position of having to find a mechanism for distributing the new-found wealth. The impact of central planning policy is, therefore, particularly vital in these states as the government will shape the course of events very directly through its spending. Most of the countries concerned are anxious to effect very rapid transformation through commercialization, the application of the most 'modern' technology, diversification of the economic base, and investment in less well-off neighbouring states, and especially since 1973 in food production. Saudi Arabia, for instance, now expends over 13 per cent of its GNP as aid, which puts it in first place among aid-giving states on a proportional basis. From the experience of the last 25 years, it is clear that the use of resources of this order of magnitude can produce undesirable results. This is particularly true when there is considerable pressure to produce rapid results, and when resources are applied to an already existing farming system in the absence of the essential research basis, and of the framework for experimentation and application, that are outlined in this Technical Note.

III. RESEARCH TRENDS 1950-1975: IMPLICATIONS FOR THE ARID ZONES

This section reviews more than a generation of research, the application of science and technology and the development experience in arid lands. As already noted, the main focus is not on individual technological aspects but on the trends, the focus and the organization of research, the relationship between research, technology and application of the results of research in the field. The next section will examine the current and proposed research by economic sector to see to what extent earlier lessons have been learned and applied.

During the period under review, there were major changes of emphasis. At the outset, the dominant element was the fragmentation of problems into artificially-separated streams. Thus there was a strict and artificial division of knowledge along reductionist lines at all levels into 'disciplines', a division which became increasingly inadequate as the need for greater integration in research and problem-solving was recognized. This division of knowledge was extremely pervasive at the beginning of this period, providing the basis for segregating subject matter in institutes of higher education, research and training. In a modified but just as critical form, it was reproduced at the decision-making level by a fragmentation of problems into sectoral ministries and departments. Within the growing family of United Nations agencies, there was a similar tendency for research to be technical, insular and rather narrow. It was also characteristic of the earlier part of this period, to conceive research in terms of science and technology; within these limits much essential and valuable work was carried out, often under extremely trying conditions. Social research, where it was carried out at all, was often conducted *in vacuo* in universities and within the very static and ritualistic preoccupations of contemporary anthropology.

In this period, several trends in the orientation and organization of research can be identified:

1. the rise of the 'commodity-research institute' (e.g. CIMMYT (*Centro Internacional de Mejoramiento de Maiz y Trigo*) in Mexico) and their gradual evolution into 'production-systems' institutes with a much broader problem focus in the process of change affecting that commodity;
2. the growing gap between increasingly problem-oriented research and the decision-making process which remained confined in the traditional framework of sectors and which continued to concentrate on the symptoms of problems;
3. a widening gap between the advances in science and technology and the lack of parallel information on the socio-economic context into which the technology had to be introduced;
4. a refocussing of research to the local, or at least national, level in the developing countries either in an attempt to evolve local solutions to local problems or to evaluate and modify imported technology for local use;
5. a shift in the emphasis towards training in the appropriate national context of the trainee's own country;
6. a growth in the realization of the need for global responses to global problems (the Stockholm, Bucharest, Mar del Plata and Nairobi Conferences on the Environment, Population, Water and Desertification);
7. the recognition of the scarcity and cost of fossil energy and the need to move away from high-energy solutions;
8. a growing orientation of research towards the production unit, i.e. the farm or the herd, as a production system.

No one can consider research in the arid zones without first thinking of the early efforts made by Unesco in the 1950's to focus attention on this least-considered area of the world. The long series of publications in the Arid Zone Research Series mirror the fragmented and narrow technical view prevailing at that time. Only three volumes in this series (Unesco 1957, 1961, 1962) represented syntheses which were unmatched at the time, and which tried to relate the purely technical state of the art to the socio-economic context. Piganiol, in introducing the Paris symposium on the Problems of the Arid Lands in 1962 stated:

> At no point in our work should we forget that arid zone development is not purely a technical problem; its aim is the well-being of men who live in such regions ... That is the reason why you have included in your work the psychological and sociological repercussions of the changes made possible by modern technology[1]. This is a vital question which has too long been neglected and its appearance here bespeaks perhaps the generous outlook of international organizations. The work of finding the new institutional framework required for adapting technical progress to particular human systems is also an essential task of your meeting. (Unesco 1962).

There was, however, a considerable gulf between what could be written at this level and what was translated into action at the level of research or application in the field. The intellectual stimulus provided by the umbrella of Unesco's programme found practical expression in the field in the establishment of arid zone centres, particularly in India, Iraq, Israel, Mexico and Tunisia. But the majority of research continued, and still continues, within the old-established divisions.

From the late 1940's onwards, there was a gradual shift of emphasis away from the systematic analysis, classification and mapping of constituent components of the natural environment, though these skills were and are essential, towards a focus on certain key food staples and cash crops. Perhaps best known in the context of the crop research approach was the work commenced in Mexico in the late 1940's at CIMMYT, concentrating on maize and wheat improvement through genetic advances. The aim at the station was to breed in qualities which would produce a grain capable of showing a substantial increase in yields per unit area. As the world moved forward into the era of post-colonial independence, attention was increasingly focussed on the problems of the Third World. The literature of the 1950's and particularly that of the early 1960's was replete with projections of a serious food shortage by 1985 as population growth outstripped agricultural productivity. It is not surprising, therefore, that the research effort was concentrated on producing the technical means to overcome the impending shortage. Indeed, it is often forgotten in the debate about the social side-effects of the 'Green Revolution', as the breakthrough came to be called, that at least in the short-term it has pushed back the spectre of famine in India and several other countries. However, it was to a large extent the experience gained by trying to implement the technical advances of the Green Revolution, coupled with the widespread destruction of rangelands, that emphasized the need for a wider and more integrated research base, though this was by no means a new plea. The undeniable benefits of the commodity research approach were achieved at a social cost which has come to be recognized. This experience is reflected in, at least, the research framework of more recent commodity-based research units.

During this period, the real problem in most of the arid zones in developing countries was the accelerating ecological imbalance and the widening gap between the supply and demand equation for food. Human and stock populations were growing rapidly in the wake of health improvements; colonial governments and their immediate successors were pressing farmers to grow more cash crops, increasing the *per capita* demand for land; and population was expanding geographically, during a humid phase, far beyond the reasonably safe limits of cultivation (i.e. the long-term average minimum precipitation). The result of this situation was serious erosion and a growing long-term over-extraction of energy from the system. In consequence, the natural resilience of these areas to withstand the expected droughts was seriously undermined, confronting governments with major human problems such as the 1961 East African drought in which the majority of Masai animals were lost. To offset this serious situation of depletion of resources, the authorities tended to opt for solutions involving the purchase of large-scale capital-intensive technology to 'transform' the situation.

It was almost impossible under the prevailing circumstances to investigate the real causes

1. It is significant that at the time what was considered the new focus was to assess the socio-economic impact of new technology rather than to develop technology for existing local production systems.

of an ecological problem such as the degeneration of rangelands. Very few disciplines or institutions had a broad enough perspective. Moreover, even if results were available on which to base proposals with the required level of integration and cohesiveness, who was in a position to apply these proposals? In the United States, a natural calamity of this order had been most effectively dealt with by redefining the terms of reference of the decision-makers in the Tennessee Valley Authority.

To take a case in point, in Uganda there was serious concern over the declining environmental situation in Karamoja. In 1961 it was pointed out that as a result of overstocking by cattle, the perennial vegetation had retreated before annual grasses at approximately 1.4 km/yr, and the people and their animals consequently had no capacity to withstand the drought of that year. This was a clear case of rangeland mismanagement. But the ecological concept of 'rangeland management' relates man both to stock and to natural fodder and water. All factors (physical, social, economic) that in any way influence this equation must be considered in research and application of results; otherwise the imbalance is merely shifted, not redressed. But in order to cope with this type of situation effectively it is necessary to consider: the carrying capacity of degraded and regenerated range; the availability of water resources; the likely offtake of animals for subsistence and marketing; the secondary social role of animals relating to offtake; the adequacy of the marketing infrastructure; the provision of veterinary care, etc. In all, at least seven ministries were involved in the Ugandan situation. At no point did the production system of the local people become the focus of their efforts, although an excellent anthropological study was available. There was a research programme into pasture regeneration, a survey of water resources and the construction of new stock routes. The short-term solution to the problem was to provide more water points and better veterinary facilities to offset stock losses. The boreholes and vaccines were, in themselves, perfectly adequate as technological advances, but their application *in vacuo* proved destructive in the absence of related offtake and grazing rotation controls. Consequently, the area and intensity of overgrazing increased.

Research during much of this period tended not only to be narrowly technical, but was mostly conducted outside the arid zones in particular and developing countries in general. In consequence, much of the technology introduced at this time often proved a serious disappointment or made matters worse, in the context in which it was applied, even though it had worked reasonably well elsewhere. Technology imported in this way was frequently inappropriate, as was the case with the emphasis on surface storage of water or heavy mechanization on fragile soils. Very often the devastation would merely spread as in the case of the boreholes mentioned above, where parallel social research would have indicated that the extra animals produced would be held *in situ*. In most cases the technology far outran the local capacity to absorb it - for example, in parts of the Punjab, providing irrigation water without providing any experience or advice to the farmer on how to use this new resource and to thereby prevent the wholesale salinization; providing tractors for tiny, fragmented farms; etc. The focus of development was on the capital and the technology, a fact which is hardly surprising considering the success of the Marshall Plan in the reconstruction of Europe.

In the arid zones of developing countries, research tended to concentrate not at the level of small farmer or herder and his survival strategy, but at the level of the Government Research Station. By the late 1950's, a great deal of primary research had been accumulated behind the fences of the research stations and the problem was 'to take it from there to the farmer'. Hence the contemporary preoccupation with 'technology impact' studies, which merely stood the problem on its head. This research, which in many of the poorer countries was overwhelmingly concerned during the colonial era with export cash crops, had a very low rate of successful extension. Hardly any research and technical development took as its starting point the basic unit of production, the farm or the herd, or worked out its results in that context. The process was always one of pushing out something new from the centre or abroad where the whole resource package, social organization and perspective was different, and was seen to be different by the farmer of herder.

This is not to say that attention to the holistic view, the peasant farm or the herder was absent. Much valuable research work of this type was done by universities and institutes. Quite often, despite the unique opportunities offered within these establishments, research workers formulated their studies not according to what the country needed, but to what their career prospects encouraged or what research grants would finance. Sadly, much of the research was irrelevant or of a low priority from the point of view of the immediate development needs of the country concerned. For instance, a great deal of social/anthropological research

concentrated on Man-Man (or even Man-Animal) relationships. There was virtually no study of Man-Society-Production relations. Also, a vast amount of valuable research was lost, buried and neglected in files, published in obscure journals or repatriated with foreign academics at the end of their short tours. Many academic researchers were still emphasizing the criterion of contributing to the total sum of human knowledge rather than considering the priority needs for research within the context of national development programmes. It is also true that many of the ideas regarding integrated research were circulating even before the Second World War, but the people with the necessary training and perspective were insufficient in number to make a major impact.

Again, even where the research was of immediate value to planners, the linkage between such findings and policy, or even projects, was very weak, universities being aloof or isolated from the practicalities of planning. In East Africa, for instance, before 1964 there were more university students of European history than of agriculture. This problem of linkage and communication emerges consistently in reviewing the research experience of the period: ministries failing to integrate their findings and work with other ministries; research stations failing to relate adequately to the mass of primary producers; institutes conducting research, often into problems of central importance, lacking integration with those responsible for action. It is hardly surprising in view of the institutional fragmentation and the great lacuna of social research at the government decision-making level, that the ecological problem of the arid zones was never effectively defined or dealt with. On the other hand, a vast amount of research of a very high order was done within the constraints outlined above, so that for some aspects of the technical problems of the arid zone the scientific research has been done and the technology produced. The results of this research cannot be applied, however, with any real prospect of success until the necessary social research is also carried out.

It is clearly not possible to identify a particular moment over the last generation at which the research emphasis began to shift away from the strongly technical bias of most of the 1950's and 1960's. The 'Integrated Survey Approach' promoted under Unesco's Arid Zone Programme, following pioneer work in Australia and Tunisia, was a first step in this direction. However, the decade of the 1970's does appear to mark a watershed, with, for instance, the launching of the Man and the Biosphere (MAB) Programme of Unesco in 1971 and the Stockholm Conference on the Environment in 1972. Before looking at the accelerating change of emphasis in research trends since then, it is useful to try and assess why the change came about.

The 1960's was a decade in which serious droughts affected large areas, particularly in Africa and southern Asia, including the onset of the catastrophic 1968-1973 drought in the monsoonal zones of these areas. As there had been in Nigeria in the 1930's and Uganda in 1961, advocates of climatic change explained the now very evident destruction of the semi-arid rangelands and the periodic exodus of farmers from areas of parched and withered crops. By this time, however, the evidence of degradation through serious mismanagement of the land had also become very clear and, regardless of hypothetical global atmospheric changes, it was undeniable that the breakdown of the energy equation and consequent diminished resilience of the land invited expansion of desert-like conditions. A fundamental question had to be asked: Why, in view of all the scientific progress and training since the war, was the situation in the arid zones visibly deteriorating at a very rapid pace? The attempt to answer this question led to a re-examination of research efforts and the reorientation of some academic programmes, the restructuring of the research framework and greater interagency co-operation.

The 1960's also provided a significant case study of the weaknesses of the 'reductionist approach' to research, when the major technical advances of the Green Revolution were extended from Mexico and the Philippines to other parts of the Third World. This last major manifestation of the 'miracle technology' approach has become the classic example of incomplete research and the problems of technology transfer. It was clear, that to obtain the greatest possible benefit from technology, the challenge must be seen to be greater than crop genetics, pesticides, water and fertilizer alone.

In parts of southern Asia and Latin America, the selective spread of High Yielding Varieties displaced or impoverished peasants who had no access to the complementary resources necessary to join the Green Revolution, such as irrigation water, drainage, fertilizer, pesticide, credit, etc. Thus divisions within society were accentuated. The HYV's represented possibly the most significant single result of applied research in the primary production sector since the war. The technical importance of the work and its potential for buying the world more

time to resolve its fundamental problem of burgeoning population and consumption of non-renewable resources cannot be denied.

Much the same lesson was being learned in irrigated areas where, despite one or two purely technical failures, the early expectations were being frustrated by problems arising from mismanagement of water resources. There were problems of salination, waterlogging and the spread of schistosomiasis and malaria in stillwater conditions in Egypt, Pakistan, Kenya, Ghana, Ethiopia and Sri Lanka, amongst many others, and onchocerciasis occurred where the flow of streams was accelerated. Similar to the outcome of unplanned expansion of boreholes in pastoral areas, productive land was actually being lost in some locations as a direct consequence of the introduction of new technology.

Further pressure for the reorientation of research and implementation came when attention began to be focussed on the local production systems which the new technology was so often seeming to break down. The question was being asked, Why are the anticipated results not being achieved when we take a tested technology from a to b? It was realized that virtually no studies existed on the energy flows, indigenous knowledge or detailed production and survival strategies of the systems into which change was being introduced. Thus it was not surprising that the responses to technology were not always those anticipated or regarded by planners as 'normal'. Even now there is a serious lack of quantified data on nearly all the basic production systems. In addition, it was increasingly evident that individual countries were replicating the errors of others at failing to carry out posterior evaluation of the problems experienced during the realization of individual projects. The amount of evaluative research is growing but is still pitifully small, and it is not difficult to see why; no agency or government wishes to publicize its errors and it is not politically expedient to commission such research. A certain amount of evaluative study is carried out by institutes of higher learning, but the linkages back into the planning programme are usually weak.

Technological advances were, themselves, encouraging a broader view of the nature of the world's problems. Remote sensing gave the world a new view of itself and a new perspective of its problems. Although systems thinking had been in existence for a considerable time, it was during the late 1960's that the widespread application of computer technology permitted the rapid correlation of ecological data. At the same time, popular awareness of environmental issues was growing and notable successes were being achieved by pressure groups concentrating on broad concepts such as 'conservation' and 'pollution' which could not be tackled within the old division of knowledge and power.

A final factor influencing the reorientation of research has been the dramatic change in the world food situation since 1973. Developing countries, especially some of the poorer ones in the arid zone, have become increasingly and in some cases alarmingly dependent upon imported food supplies which tripled in price between 1973 and 1975. The 'world food crisis' has focussed attention onto improving the indigenous subsistence base of individual countries[1], and conserving productive resources, helping to insulate these states from this fundamental difficulty and attempting to reverse a trend of increasing dependence at this most basic level. Outside the primary production sector there is a growing awareness of the fact that western mass-production technology has often had the effect of almost completely destroying local crafts such as woodworking and leather working, reducing opportunities for those increasing numbers of people displaced from the land, and swelling large bureaucracies or shanty towns of the peripheral urban unemployed or underemployed. Very little attention has been focussed on researching manufacturing or craft opportunities at an appropriate level, e.g. making animal-draught tools from old vehicle parts, often because governments consider such activities as 'second class' technology and aspire to acquiring the 'most modern', even though it is almost inevitably labour-saving. This attitude is even more inappropriate at the present time, as so many of the 'modern' technologies are founded upon the era of cheap fossil energy which came to an abrupt end in 1973-1974. The poor states of the arid zones find this type of technology dragging them deeper into a state of dependency and imported inflation.

The literature of the early 1970's is replete with cries for a reorganization and reorientation of research and the development of associated technology; the following quotation from a report of the Commission for Social Development of the United Nations Economic and Social Council (United Nations 1975) is typical:

> It is now evident that a technical innovation or a policy with regard to technological research or choice of production technique,

1. Now a priority of the planning for the reconstruction of the Sahel and the principal area for the investment of Saudi funds in Africa.

> which has worked satisfactorily in a developed country, may not transfer effectively to a developing country where the surrounding circumstances are different. Even when such a transfer is technically successful, it may not serve the ends of participative and organic development. The benefits may be confined to a better-off minority even when the intention is to benefit the total population or the masses of the poor in particular. This applies to technological transfers broadly conceived to include social and re-distributional techniques.

The main research trend during the 1970's has been to create the administrative or organizational structures needed to enable and encourage the integration of scientific and social research. A major step already mentioned in this direction was the launching of Unesco's Man and the Biosphere (MAB) Programme, which has its methodological roots and operational framework in systems research. MAB Project 3 is concerned with the impact of human activities on grazing lands in arid areas. The methodological approach of the research effort is described as follows:

> It is thought that systems and modelling approaches could provide the conceptual frameworks and analytical procedures necessary for the resolution of these tasks. The terms 'systems analysis and modelling approaches' are used to denote both the wider employment of mathematical concepts in ecological research and particular submodels of these concepts. The whole range of these approaches can play a crucial role in helping to bring about a greater coherence and significance of ecological research, and in advancing the understanding and optimal utilization of renewable natural resources. The bases of systems and modelling approaches is the concept of integration, a concept which is central to the MAB Programme (Unesco 1972).

In addition, the MAB Programme emphasizes the participation of local staff from the country in which research is taking place.

Parallel to the MAB initiative, has evolved a whole family of research institutes with an arid zone bias or interest, organizing their effort according to ecosystem or other integrating principles. It is not possible to provide an exhaustive catalogue of all of these, but attention might be drawn to the following as examples of the trend.

The Consultative Group on International Agricultural Research (CGIAR), which now acts as an umbrella organization co-ordinating multilateral, bilateral, agency and non-governmental organization funding, has three institutions of special interest for arid zone research - all products of the 1970's. The first is the International Livestock Centre for Africa (ILCA) in Addis Ababa. In its prospectus, ILCA explains why it has organized its research on a systems basis:

> The systems approach is valuable both for identifying development strategies for immediate use ... and for selecting areas for research. Its value in research planning lies not so much in identifying problems which are often self-evident, as in selecting what are likely to be the most profitable approaches to problem-solving.

This would certainly seem to be too hasty a dismissal of one of the most rewarding aspects of adopting the systems approach, for only with this breadth of perspective is it possible to define the 'problem'.

The second CGIAR centre of direct importance to the arid zones is the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) at Hyderabad in India. This centre has a section dealing with research on farming systems, which involves the entire complex of development management and allocation of resources as well as all decisions and activities which, within the operational unit or combination of such units, result in agricultural production. The processing and marketing of the products are also directly related to the system that produces them. The inclusion of farm systems as one part of the research programme is in contrast to the ILCA approach, where it is the central focus of the research effort. The division of skills within the latter institution has, however, been a purely conventional one. One further aspect in the design of ICRISAT's programme of considerable significance is the attention it pays to basic subsistence crops like chickpea and pigeonpea.

The third and most recent initiative of CGIAR is the International Centre for Agricultural Research in the Dry Areas (ICARDA) based at Aleppo in Syria, which is envisaged as a systems centre with the farming system and its underlying water constraint providing the framework for improved cereals and legumes and their integration with annual ley pastures and sheep.

So in each of these centres the research focus apparently moves towards the 'production system' or, more prosaically, the farm, the herd and the flock. This shifts the point of attention off the research centre where the optimal research environment is created before the technical work starts. The problem remains

of how to get the findings to the farmer, i.e. how to deal with the fact that he is brought in when the process is completed. The traditional research centre environment encourages abstraction and a concern with technical and academic research *in vacuo*, and detaches the research effort from its essential roots at the production system level. The alternative might not appear so prestigious, or even academically satisfying for the conventionally-trained researcher at the fenced-off research station, but it is unlikely that the success rate of applying or transferring research will rise above its present poor showing until this is done in the developing countries.

Apart from the three examples cited above, a whole array of integrated research institutes or programmes have adapted to the changes in intellectual climate, including the Institute of Deserts at Ashkhabad (USSR), the Ben Gurion University in Israel, the Central Arid Zone Research Institute at Jodhpur in India, the Abu Ghraib Institute of Integrated Studies in Iraq, the Sahel Institute in Bamako, the Ecological Management of Arid and Semi-Arid Rangelands (EMASAR) Programme of FAO, amongst others. In addition, interagency co-operation within the United Nations family has been instituted through liaison posts and secondments.

Clearly, the institutional orientation of research has undergone a substantial change in the last six or seven years, but there are still serious identifiable weaknesses in the research and planning process which may be summarized as follows.

Firstly, it is very often difficult to relate the actions, projects and programmes of many of the new institutions to their stated commitments to integrated research. All too often, mere lip service is paid to the systems focus, whilst individual specialists continue to work in their own narrow field in well-defined disciplinary units. Frequently the subdivision within these institutes into sections along traditional lines has caused them to replicate the very problem they were designed to overcome. This is a very natural process as individuals are, and will continue to be, trained as specialists and will naturally gravitate towards the pursuit of their chosen specialism. There is no substitute for specialist skills, nor is there any question of considering a systems approach as a kind of substitute. It is how the technical skills are applied, and how the branches of science, including social science, relate which is critical. It takes more than a statement of intent or an institutional framework to produce a new approach. It requires on the part of the directors of such institutes, commitment, belief, a strong sense of innovation and a conviction that the new methodological framework is essential, coupled with an understanding on the part of researchers that they have much to offer to, and learn from, their colleagues according to the old adage that the 'whole is greater than the sum of the constituent parts'. There is clearly a need for greater institutional flexibility so that the skills within an organization may be brought to bear on problems in the most productive way. Similarly, skills in different agencies should be brought together to tackle problems in a more flexible way.

Secondly, there continues to be a widening gulf between what happens at the research level and at the level of implementation. FAO/EMASAR has noted (FAO 1974) that one guiding principle for future development should be 'support ... only where effective local and national organizations are established (as part of the programme) with capability to service such development'. This statement refers to the fragmentation of decision-making along traditional sectoral lines of responsibility; for example, how does one tackle a concept such as 'mixed farming' when one has, as some countries do, a Ministry of Agriculture and a Ministry of Animal Production? At this point one enters the realms of politics, for between the results of ecologically sound research and the implementation of ecologically appropriate solutions, both of which are defined by the factors involved in drawing up a balanced energy equation, lies the 'Administrative Trap'. Until politically acceptable solutions can be found at the national and subnational level, the systems approach to research will have to find its expression at the level of implementation only after having been squeezed through the prevailing reductionist systems of decision-making.

In addition, many authorities in government have to respond to pressures for immediate action rather than further research, a dilemma which has, on numerous occasions in the past, led to the mass transfer of technology from the developed world in the hope that rapid and visible results would accrue. For its part, the developed world has encouraged this process as there is an immediate profit to be made from the sale of existing technology in packages whilst there is little profit in performing basic research at the field level. To understand fully the application of science and technology in the arid zones over the last generation, a whole range of 'X' factors would have to be taken into account, such as perceptions of modernity instilled in the developing countries by a colonial past. This has had the effect of

convincing many people in developing countries that 'development' equates with what has taken place in the metropolitan country, using the same methods and technology. A corollary has been to detract from the research of indigenous production systems, technology and knowledge. In some cases the process has been taken to the point where planners in some developing countries lump all this experience together under the heading of 'primitive', a term used in a pejorative way, and concentrate instead on the technological miracles of the developed world. It is instructive to follow a party of visitors from the Third World around a European country on a sponsored visit. In agriculture, for instance, they are shown fields and quoted extremely high figures of crop productivity and shown the machinery involved. To a large extent it is factors that cannot be seen, such as credit, management and training, information and marketing systems, and intense basic research, which produce the yields, not just the production technology. Add to this impression, pressure on the politician for quick results and high-pressure salesmanship from the developed countries, and it is clear why there is so little expression of the new research orientation at the planning and project implementation level.

Thirdly, there has been a preoccupation in the past with sending students to noted centres of learning in the developed, temperate world to study in a context which is completely different economically, technically and socially from that of their own countries. It is not surprising, therefore, that the research and development actions which result have an inappropriate or import-oriented bias emphasizing capital substitution and high-energy dependency. The learning process should be firmly rooted in the realities of individual national situations.

Finally, all too often there is an excessively institutional response to problem-solving. By this it is meant that ecological problems upon which, increasingly, interest is focussing, cross the boundaries of many existing institutions all of which feel they should make some response. For instance, grazing land problems in northern Africa now fall under the terms of reference of the appropriate national ministries, Unesco/MAB, UNEP, FAO/EMASAR, ICARDA and a new rangeland centre being proposed in Libya for northern Africa and the Near East. It seems that fragmentation, which has beset research for a generation, is in danger of repeating itself at a different level. Added to this is a danger that the proliferation of the research effort at this level will spread the expertise too thin at a time when it is becoming increasingly difficult to find persons with experience, training and a willingness to work at the most basic level. There is danger of an explosion of highly-paid, short-term foreign experts who will not be able or willing to make the new research orientation a working reality. One consequence of the global conference approach to world problems has been the spawning of ever more institutions. This reduces the number of people available for practical work in the field and further divides the research effort into many parallel streams. The Desertification Conference in Nairobi fortunately resisted this trend and concentrated on developing better linkages between the already existing skilled staff in different agencies.

IV. CURRENT TRENDS IN RESEARCH, AND THE APPLICATION OF SCIENCE AND TECHNOLOGY IN THE ARID ZONES BY ECONOMIC SECTOR

In this section, attention continues to be given to indicating trends rather than to listing individual research efforts.

PRIMARY PRODUCTION

Rainfed agriculture

Rainfed agriculture is, and probably will remain, the basis of food crop production in the arid zones of the developing countries. As would be expected from the orientation of research since 1970, as outlined above, attention has increasingly been concentrated on understanding and quantifying the existing production systems so that their efficiency and energy flow characteristics are clear. Work is processing at a number of centres along systems lines, to assess the productivity of crop and livestock systems in their local environment. In addition to research within the MAB Programme of Unesco, an energy balance is being drawn up for the Tuareg of Algeria/Niger. Similar work on the Bedouin of the Negev is being carried out by members of the Desert Ecosystems Project at the Sede Boqer branch of Ben Gurion University. Definitive results are, however, not yet available at this early stage in the life of most of the ecologically oriented institutions.

A more complete understanding of food production systems at the farm or herd level will serve the following purposes:

- indicate the potential and limitations of the traditional resource-use methods, i.e. the difference between what is hoped for and what is possible;
- illustrate the overall context of constraints under which producers operate, and the strategies and tactics they utilize;
- bring into focus a traditional fund of environmental knowledge; and
- emphasize the 'package' approach to agricultural development, as it is now clear that any real improvement will depend on comprehensive, not piecemeal, change.

It is being shown that there is an essential rationality and complexity to the individual producer's strategies in eastern and western Africa. Amongst the cultivators of the wetter margins of the arid zone, intensely detailed adjustment to risk, aspect, soil and rainfall variability are emerging. However, the problem is that what once may have been rational for the individual is no longer rational for the community under intense and growing population pressure. Hence the need to consider systems in the context of the production unit and of aggregated production units. At present, efforts are concentrated on reducing risk and increasing productivity per hectare in order to cater to greater numbers of people. Clearly, it is essential that this research on genetic improvement, fertilizer trials and other technical aspects be seen in the context of research and development in other sectors, in order to relieve pressure on overtaxed land resources, i.e. by migration and employment outside the primary sector. It has already been shown in both the southern Hejaz and the Yemen that over half the cash income of farming families is derived from remittances sent by migrants in the urban areas. Thus, what happens on the farm may well be intimately linked with what is planned for the manufacturing and service sectors. Again, there is no value in investing in improved farming, and virtually all productivity increases involve the substitute of purchased inputs for labour, if the credit, marketing and other facilities are inadequate.

Once one approaches this level of comprehensive integration, very considerable demands are placed on the research, planning and decision-

making apparatus, demands which go beyond the usual systems brief of the new research institutions. But in this situation, there has also been an attempt to learn from the experiences of the past. For example, India has set up special administrative units for the 'drought prone areas' and Niger is considering an umbrella ministry for the problem zone. Whether or not the research orientation at the primary producer level is broad enough to prevent a repetition of the negative aspects of the Green Revolution syndrome has yet to be seen.

At the technical level, where research has been carried out for some time, work on plant breeding and agroclimatology is now being focused on the longer established food crops to breed in, wherever possible, greater drought and disease resistance. For instance, at the Central Arid Zone Research Institute (CAZRI) in Jodhpur, India, current research is investigating Crop Production Technology for the delayed onset of the monsoons and methods to combat desert rodents, as well as developing high yield varieties of local crops such as *bajra* (millet) which are adapted to conditions in India.

Countries of the arid zone, through institutions such as the ICRISAT, have made use of the pioneering work of the CIMMYT in Mexico, but as far as possible the emphasis is now being placed on rainfed crops as well as the more familiar irrigated maize and wheat varieties grown widely in Mexico, Pakistan and Algeria. One example of such work is directed towards minor millets of short duration and with low water requirements being carried out at Hyderabad. Another example are the ICRISAT studies on fertilization, date of planting, variety comparison, innoculation effects and intercropping of sorghum, pearl millet, pigeonpeas, soya bean and various winter crops such as chickpeas, under local rainfed conditions. This research is not directed at the extension of rainfed cultivation towards the drier margins, in the way that shorter-maturing varieties of cereals permitted the expansion northwards of the cultivation frontier in Finland during this century. It is generally felt that most rainfed agriculture has already proceeded too far beyond the 400 mm summer rainfall isohyet. Research is directed towards consolidating agriculture in the areas on the humid margins of the isohyets. ICARDA will concentrate part of its research effort on the evaluation of seed-bearing legumes which can allow for the elimination of fallow in areas of winter rainfall, improving also the yields of succeeding cereal crops and reducing the dependence upon fossil fuel derivatives, which are often too expensive for the small farmer to use to maintain and enhance fertility.

The research effort of ICARDA is notable also for the fact that it brings together, after an almost traditional separation, the livestock and crop sectors. The separation of these two elements at the research and planning level reflected a process which was becoming increasingly noticeable in the arid zones at the level of production, as the two communities were in increasing competition for land. The emphasis is now coming back to integration with the cultivation of nitrogen-fixing legumes in rotation. This emphasis in turn reflects a trend in many parts of the Middle East and northern Africa for nomads to become more settled and to practise a form of semi-nomadism based on a fixed-farm location. In this way, a new relationship between the desert and the sown may emerge, for much social research in Arab countries, and northern Africa is dismissing the myths about the nomad, his romantic attachment to his animals, his peripatetic existence and his scorn of agriculture. It is now very common for Bedouins in south-western Saudi Arabia to be settled farmers with seasonally-dispersed herds; the settlement scheme in Tayma based on fossil groundwater, was very quickly oversubscribed with applications for land, almost all from Bedouins.

In contrast to the high technology which continues to dominate much of the development effort in the arid zones, even in the developing countries, there has been a growing research interest in minimum tillage (animal-draught) systems. The main attractions of such systems are that:

- they may be constructed locally and maintained at little cost;
- they can overcome the principal labour bottlenecks of breaking the soil at the onset of rains, weeding and, to some extent, harvesting;
- they are related to resource levels and technical capacities of the majority of farmers;
- and they are not dependent upon soaring energy costs.

Research has produced workable toolbar devices in Botswana and southern Darfur (Sudan) amongst other locations, but the rate of takeup has been depressingly slow, partly because this is still viewed as 'second class' technology in countries which want 'the best'.

At the root of all dryland farming remains the basic problem of rainfall variability. It will take many decades for meteorologists to be able in any way to reliably forecast the onset of the rains. This fact is now generally appreciated by planners in the arid zones, despite

some speculative remarks which were made in the early days of LANDSAT and ERTS satellite development. Answers cannot be readily provided to the key questions of climatic change and weather forecasting, as the time series of detailed data or the technological capacity remain inadequate. This considerably reduces the capacity of planners both in the short- and long-term, but development will have to proceed within the limits of these uncertainties within the foreseeable future.

Perhaps a more promising approach in the immediate future lies in the better use of available climatological data with the associated improved data banks and of more agroclimatological studies and services. There is currently an agrometeorological pilot project (AGMET) about to commence in the countries of Africa west of Libya, Chad and Cameroon, whereby every ten days raw climatic data will be collected and analysed at a regional centre. Processed information will be disseminated for use with national agricultural information at both the national and local level.

At present, research is concentrating on agroclimatology with one major effort being centred in Niamey (Niger), where the WMO Sahelian agrohydrological-meteorological project is located. This project is directed first at training indigenous specialists in analytical and recording skills. At the same time, basic work in crop water requirements will be carried out which will be mirrored in other parts of the arid zones by the Global Research Project in Agricultural Biometeorology jointly sponsored by FAO, WMO and Unesco. This project has the following objectives:

1. to carry out a programme of simultaneous agrometeorological and biological observations on selected wheat varieties and to study the problems of introduction and adaptation of wheat to various environments;
2. to provide agrometeorological and biological data allowing the elaboration of calculation schemes for the forecasting of crop production;
3. to determine the agrometeorological and biological factors limiting crop production;
4. to design and test techniques and methodology for the study of wheat-climate relationships.

The initial pilot phase is concentrating upon Ethiopia, Senegal, Nigeria, Tunisia and Morocco, with both irrigated and rainfed stations.

As a consequence of the events of 1968-1973, a great deal of attention has been directed, especially in the more popular literature, towards halting the 'advance of the desert' into zones of cultivation. In only a few locations is the solution one of checking the physical creep of dunes into farmland; more often the deserts are created *in situ*. Thus, research has tended to move away from the 'green wall' concept towards broader lines of better land management and the retention of a basic ecological balance. In some areas of China, the Sahel and Algeria, an assessment is being made of the role of forestry in holding the present frontiers and the use of forestry as part of a rehabilitation programme. A wider study by the Forest Resources Division of FAO has produced a guide to conservation practices in the arid and semi-arid zones (FAO 1976) in an attempt to bind and consolidate the marginal areas of cultivation against further degradation. These practices include shelterbelt techniques, grass barriers, catchment protection, anti-erosion cultivation techniques and, in some states of Arab countries and northern Africa, the costly spraying of dunes with oil by-products. In some areas, conservation technology emerges as the most immediate priority in preserving the resource base of the arid zones. The most dramatic example is that of the Yemen referred to earlier, where higher terraces are being abandoned. These terraces, no longer cultivated, develop an algal cover and are effectively sealed against water, causing it to cascade onto the terraces below and thus to carry erosion and destruction downwards. Stabilization of the upper terraces through forestry and forage shrubs is a matter of urgent priority.

Over the many years during which the question of climatic change has remained unanswered, work has proceeded on more local weather modification. It is not yet possible to prove, in any scientific way, a similar response in the monsoonal areas, but WMO, through its Precipitation Enhancement Project is sponsoring the essential studies into cloud physics. Only after at least five or six years of trial will it be possible to ascertain whether the process of rainfall enhancement has any real proven significance in a given local situation. Trials in Saudi Arabia are due to start shortly with a WMO-organized cloud seeding project.

Irrigated agriculture

As with pastoralism, irrigation is an area in which early expectations have very frequently been frustrated and the environmental effects of the introduction of technology have often been negative. Shortsighted projects have neglected the effects on soils (salinization) and plants (waterlogging), on inadequate drainage, although the technical experience in a number

of countries, including Hungary, Pakistan, the United States and the USSR (FAO-Unesco 1973), has been to avoid such mistakes. In Hungary, for example, the problems of alkalization and salinization on large areas of the Hungarian plains had led to major research undertaken by the Research Institute for Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences in Budapest.

The problem of irrigated agriculture is also one of management, or rather lack of management and training, which can result in the serious misuse of water, causing salinization (Pakistan, Egypt), waterlogging (Iraq) and the spread of human disease (Egypt, Sudan, Ghana). The expectations from irrigation were very high in the early post-war years, and the technological preoccupation was, perhaps, greater in this area than in any other. International organizations such as WHO are often consulted only once problems have already occurred, examples being the Volta Dam, the Kainji Dam and the Kariba. To avoid such problems, integration in research and planning is called for, such as in Worthington (1977) where it is recommended that the following questions be taken into consideration in any proposed irrigation and drainage scheme, in addition to the economic questions of prospective flow of costs and benefits:

1. Has adequate provision been made for drainage and leaching so as to permanently maintain the quality of the soil and water in the root zone?
2. Has the full range of alternative measures for achieving efficiency in water use been appraised?
3. Has the project study examined the probable effects upon aquatic and adjoining terrestrial ecosystems of changing the hydrological and soil regime in the area?
4. Has the study canvassed and assigned costs to the social, health and economic measures which would be required to ensure that anticipated benefits from crop growth and social stability are realized?
5. Has the well-being of the population been taken into account?

In this context attention should be drawn to the environmental impact study funded by the United States Agency for International Development (USAID) for the OMVVS (*Organisation pour la mise en valeur de la vallée du fleuve Sénégal*) in connection with the proposed Senegal River Basin Programme. Prior to the initiation of any investment, the following effects will be studied and evaluated:

- physical changes in the river which could be caused by changes in the stream flow regime;
- sociological effects of the displacement of populations in the flooded areas and such impacts as changes in types of employment and income;
- spread or inhibition of disease vectors resulting from changes in stream flow, water storage, irrigation systems and flood control;
- sociological and economic changes linked to the establishment of a year-round navigation system, provision of electric power and the introduction of irrigated agriculture;
- water quality and air pollution problems;
- changes in marine and land animals and plant life;
- changes in farming methods with the availability of surface irrigation and independence from natural river flooding.

In FAO, the emphasis has shifted away from the extension of irrigation technology in new areas to the rehabilitation of existing schemes, in an attempt to make better use of the water already being extracted and to prevent any further loss of land through degradation. It is also recognized that the solution to many of the present difficulties experienced with irrigation schemes rests with improved management. There is little doubt that the success of the often-cited Gezira Scheme is the very firm central control over the use of resources. However adequate the technical preparation of an irrigation scheme might be, it is essential that the management system be well conceived and effective from the beginning. In many cases in both the developing and the developed world, overpumping of groundwater or indiscriminate sinking of boreholes continues despite warnings from researchers, in order to satisfy short-term political expediency. Recommendations are still being made to the effect that in the absence of a planned grazing system, water should be denied to nomads. How to implement such a policy or who precisely will be responsible for turning off the tap, is not specified. Consequently, such recommendations are not carried out.

New technology is making possible much more efficient use of existing irrigation resources through, for instance, the spread of drip irrigation in place of the surface delivery or sprinkler systems which often result in half, or up to 80 per cent, of the water being lost before it reaches the plant. The drip-feed system, now widely used, also allows the direct feeding of nutrients to the roots of the crops rather than their distribution over the whole field. One interesting use of drip-feed has been in the establishment of tree belts in

Abu Dhabi to the point where the root systems can tap groundwater. In some dry areas, communities now function with a fully automated irrigation system controlled by computer, a system which delivers water electronically by night according to a prearranged cropping programme. It is estimated that at least 50 per cent of the water is conserved in this manner as well as 20 per cent of manpower time.

Too often town and country compete for water and, in that struggle, the townsman is predetermined to succeed. Once a pipe system is provided to urban dwellers, *per capita* consumption increases dramatically by 400-1,000 per cent, depending on the charging system and the predilection for gardens. The flourishing greenery of Jiddah's gardens with their eucalyptus, limes, pawpaws and bananas has been achieved at the cost of the agricultural swathe of the ancient Wadi Fatima. There are now plans to recycle much of the urban water as treated sewage effluent to support tree crops and lucerne. Similar proposals have been made for the effluent of Tel Aviv, and already fields of cotton and *medicago* are grown on this basis near Beersheba. Cities of many millions of inhabitants, such as Cairo, have already been constructed on the edge of the desert. The use of water in most of these cities contrasts sharply with its value in the arid zones, and it seems likely that the present profligate use of urban water will give way to recycling, aquifer recharge, crop production, etc. It has been suggested that in the development of agriculture in the arid zones, one element in the planning process should be to consider the returns per unit of water since this is the principal scarce resource.

It does not seem likely that heat-exchange systems of solar energy or other desalination processes will be able to overcome the economic problems of providing water for agriculture in the foreseeable future. Work continues on the development of power-water-food complexes and desalination of brackish water, but only in the most exceptional economic circumstances is any practical application likely on an extended basis, such as for tomato cultivation in California. Heat-exchange solar pumps were long thought to offer a more likely avenue of substitution for fossil fuel, but this system requires fairly considerable maintenance, and by working through a heat-exchange mechanism much of the energy is lost in the conversion. Recent advances in the development of photovoltaic cells have been used to develop a process which requires almost no maintenance over an approximately ten-year period and converts the solar energy directly into useable power. At present the cost is prohibitive, but the system is becoming much more attractive as the cost of alternative fossil energy rises. Scope also exists for more widespread use of thermal winds. Both photovoltaic and wind pumps could take advantage of energy in the form and at the time it is available, and store it in the form of water held in tanks.

Prospects are now being more widely investigated for the use of saline or brackish water. Some traditional systems, such as those based on date palms in Tunisia, have long flourished using saline water. Research is now concentrating on the utilization of other salt-tolerant species such as cotton, sugar-beets, rye grass, olives, pistachios, wheat, and fodder crops using saline water. At the same time, work is being done on the cultivation of protein-rich algae (especially *spirulina*) using brackish water.

It is clear that the emphasis has broadened very considerably away from the concentration on surface storage of water, with its attendant seepage and evaporation losses (often over 3 m/yr in the arid zones), to subsurface storage, better management and the conservation of water.

Livestock

There is a sharp contrast within the arid zones between those regions, such as the United States, USSR, Australia and Patagonia, where livestock is raised commercially for meat on a capital-intensive basis, and regions such as the Sahel and northwest India where animals are part of a labour-intensive, subsistence system based on milk and other recurrent products. This is one of the main reasons why it has not been possible to transfer research results very successfully from the former to the latter region.

Research is at present focused on the ecology of pastoral systems, as exemplified by MAB Project 3 on grazing lands in, for instance, northern Kenya. It is only through such work that such fundamental ecological terms as 'carrying capacity' come to have real meaning in the extremely variable conditions of the arid and semi-arid zones. Only now are we beginning to appreciate, as data become available, the productive capacity of traditional flocks and herds as related to the food requirements of the herders. In parts of eastern Africa, only 12 per cent of nomadic animals yield milk at any given moment. This situation, in a risky environment, provides a better explanation of the 'numbers mentality' of many pastoral communities than a preoccupation with pride or prestige. The herd size is the subsistence community's 'life insurance' policy

against drought. This strategy is now seen to lie at the root of any thinking about induced change or closer incorporation of these production systems into a more specialized, interlocking commercial economy.

A first priority in research in some livestock zones is to assess the capacity for regeneration and to enact new forms of control and land management, or to provide a population safety valve through migration which will prevent further degeneration of the rangelands. Satellite imagery has very dramatically revealed the impact of overgrazing and the potential for regeneration as, for instance, in the Ekrafan ranch in Niger.

Once the capacity of the land at the local level has been assessed, the major problem of enacting an improved management system arises. As long as the present dietary preferences of most cattle nomads prevail, there seems little hope of any serious change. Sheep and goat herders in northern Africa and in the Middle East are adjusting to a different life style very rapidly. They are being woven into the fabric of the commercial economy to a large extent because they have rarely been dependent upon animals for subsistence and have traditionally been carriers, middlemen and traders. Most of the semi-arid grazing zones are now recognized as being valuable mainly for breeding purposes, the fattening and finishing of animals taking place on fodder and crop residues as part of food-production rotations along the more humid margins or as part of an irrigation system. The principal barrier is still a social one, deriving from the nature of the cattle subsistence economy and its associated social values and norms. However, insufficient attention is still placed on the study of the interaction between the farming and pastoral systems. This is unfortunate, as they are interlocking systems and their individual development is best seen in terms of the development of these interrelationships.

The potential exists to increase productivity very substantially in the livestock zone through:

- disease control which has the capacity to eliminate most of the enzootic and epizootic threats;
- pasture regeneration;
- genetic improvement;
- fodder and supplement production;
- improved water provision;
- better land management.

This is a major example of a situation where, although the technical capacity exists, it fails to cross the social barrier. For the nomadic producers to change, they must become dependent on external factors which are often inadequate or exploitative, such as the market and price system, purchased food supplies, credit and advice. These facts make apparent once more the need for an integrated approach to research and development. In this area, concentration on the demonstration effect at an appropriate level seems to be the most profitable approach, i.e. researching and building on what already exists. It is very difficult for a herding community to identify with a 100,000 ha government ranch. In this respect, the Masai Group Ranching System in Kenya represents an attempt to build on the existing community. The key to change rests with demonstration, training, fair pricing and tenure reform without which no change of improvement is feasible.

Within the arid zones, research continues into the productive potential of the local ecosystem, as exemplified by the MAB-UNEP Integrated Project on Arid Lands (IPAL) in northern Kenya and the Parcours du Sud Project in southern Tunisia. Possibilities exist for expanding the use of cacti, acacias and atriplex in Syria and Iran as fodder shrubs. The same is true for *Acacia albida*, which displays the phenomenon of reverse seasonality, thus producing its pods at the time of greatest food shortage. Research is also taking place on the revival of traditional pasture conservation methods such as the *homa* system of Syria and Saudi Arabia and the *gdal* of Tunisia. In western Australia, work on subterranean clover has highlighted a prospect for areas below 500 mm rainfall. The karakul Institute of Samarkand (USSR) is a major example of where the technical capacities have been applied to increase a specialized production of high economic value in the form of astrakhan fur. A further area of research designed to make better use of the indigenous ecosystem is in game cropping or ranching and, in this field, Mali has proposed a project for funding which would investigate the broad-spectrum grazing and browsing of wild ungulates as a food-producing mechanism, complementary to the present preoccupation with cattle in that country. Many game animals, for instance, can make use of moisture trapped in vegetation.

SETTLEMENTS AND URBAN DEVELOPMENT

At one time, great desert areas and semi-desert fringes of the world supported sizeable urban populations, such as, for instance, at Petra, Tayma, Timbuktu, Gao and Palmyra. It has already been pointed out that many of these settlements collapsed, not for physical reasons,

but as a result of political changes. In many cases there is no physical reason why settlements should not once more flourish in these areas. However, many of the earlier settlements were associated with trading routes which have subsequently been bypassed, and consequently eliminated the *raison d'être* of these townships. It is questionable whether the agricultural systems which once supported some of the settlements, such as in the Negev, would prove attractive to populations with twentieth-century expectations. Research into the resuscitation of earlier water management systems may yet bring some of the desert townships back to life. What is missing at the moment is a new economic function to attract people, and to hold them, to an arid environment. The recent development of urbanization in arid zones has taken place particularly in coastal or peripheral locations. For instance, the growing concentration of population along the coastline of northern Africa can be compared with the almost totally peripheral location of capital cities in many Sahelian countries, e.g. Niger and Chad. In many countries of the Middle East such as Saudi Arabia, it can be said that urban areas are drawing away the majority of the population increase from the agricultural and pastoral zones. The corollary of this is that cities such as Riyadh and Jiddah are growing at over 8 per cent and Tehran at 10 per cent/yr. This raises the continual spectre of urban growth outpacing the provision of basic services, so that the service network has to be superimposed over an already existing distribution of dwelling and work places. Many countries in the Middle East are now engaging in major master planning exercises in order to phase the infrastructural investment in advance of population growth. One of the consequences of rapid urban growth, and much more rapid *per capita* growth in water consumption by urban dwellers, has already been referred to in the case of Jiddah where urban water consumption has been satisfied at the expense of agriculture.

Some of the urban growth in peripheral areas can be attributed to increasing opportunities in tourism, industry and the service sector. There has been very little growth of corresponding opportunities in the urban sector of the arid zones themselves. Exceptions are the mining settlements which frequently develop very rapidly and often in an unplanned way. In general oil does not enter this picture very significantly, as most oil extraction is done automatically and the bulk of employment is concentrated at the refinery or export point on the coast. The mineral towns usually have a very large transient population of, on the one hand, foreign experts and technicians who live at a very high level of energy and water consumption, and, on the other hand, an equally transient population of very much casual labour. In general this situation does not offer any long-term alternative to the well-established drift of population from the over-populated arid zones. Some countries, such as Israel, are anxious to de-emphasize a concentration of population on large urban settlements, particularly in the coastal belt. This involves decentralization of industry often far into desert zones. The industries concerned, with the exception of mineral-based enterprises, are rarely specifically adapted in any way to arid conditions. But their displacement from the main centres of population is often offset by subsidies and a very efficient transport network.

In some parts of the arid zones, particularly since the effects of the droughts of the 1960's and 1970's, nomadic populations are spontaneously settling down. This is generally in an unplanned way, and where planned provision has been made for nomads it has very often proven very unsuccessful. Experience would seem to suggest that a site and service concept incorporating a large degree of flexibility is the most practical approach towards introducing planning into the settlement of nomadic populations. Uncontrolled spontaneous settlement raises problems with regard to the provision of physical infrastructure and social services. It is extremely difficult and expensive to provide fixed urban-style educational and health services for a population which is thinly spread over a very large area. In some areas the site and service concept is being used as a means whereby an hierarchical structure of interrelated settlements can be evolved. By this means, each level of centre can have the services appropriate to its size and interconnections with larger and smaller centres. In order to achieve this degree of integration in settlement planning, several governments have opted for a regional planning framework in order to relate the settlement planning to the overall resource provision of recognized physical economic zones. Such a proposal has been recommended in Saudi Arabia, and some work has been done on identifying existing settlements. The aim is to record these settlements at their appropriate level in each region and to incorporate them within a structured hierarchical plan, including the identification of those areas which have to be planned on the basis of future decline. This task, as with so many others already mentioned, requires the

integration of many aspects of planning, including transportation, public utilities and social services. In the case of Tanzania, the effort has been directed towards bringing a scattered population into a village system, as a precursor to developing a network of social services and public utilities in the rural areas.

With respect to the individual dwelling unit, traditional forms of architecture, which were largely a form of adaptation to climatic conditions, have been replaced, since the Second World War, by standardized units derived from more humid or temperate zones. This orientation was encouraged in the 1950's and 1960's by the extremely low price of fossil fuel energy which made possible large-scale air conditioning and space heating. Architects almost invariably design their buildings for visual effect or according to some concept of social organization and space. Very rarely is energy consumption a starting point in the design of a building. This is particularly well illustrated by many of the low-cost housing schemes at present being developed in northern Africa. The rapid increase in the price of fossil fuel energy has made such an approach obsolete. A first step in this direction has been taken by the United States in commissioning a survey of energy consumption in all government buildings so that standards may be established; future buildings will have to be designed according to set energy standards. At the same time, much work is being carried out on incorporating technical advances in solar heating and cooling and the storing of solar energy in gravels to provide a pleasant and cheap living environment throughout the year.

Recent research on the effect of building design and materials on the indoor climate and on the energy needed to provide comfortable conditions, has demonstrated that the following principles are of basic importance:

1. Providing high heat capacity to the external partitions of the building. This feature can minimize the internal diurnal temperature fluctuations and, if coupled with other design features, can stabilize the indoor temperature at a level close to the comfort range.
2. Problems which are usually related to the use of such materials in rural (or shanty town) circumstances, without special internal and external finishes, include poor hygienic quality and sensitivity to rain erosion. An urgent area for research is therefore the development of low-cost, simple and durable rendering techniques, which will provide rain and insect resistance as well as the possibility of easy cleaning.
3. External reflective colours, such as lime whitewashing, of the building envelope, especially the roof and eastern and western walls, can significantly lower the indoor temperature in summer and minimize the solar heat load and the need for cooling.
4. Contrary to the opinion expressed by some writers on desert housing, ventilation is very important for thermal comfort in dry climates, especially in spring, fall and on summer evenings. Large windows, protected by closed insulated shutters during summer daytime and winter nights, can provide ventilation when needed without excessive heat gain and loss. Protected southern large windows can provide significant solar energy for direct winter heating of the interior, while the high mass prevents overheating during daytime and stores the energy for night heating.
5. Summer cooling by outgoing nocturnal longwave radiation can be provided by simple methods, with the cold thus collected stored in the high mass of the building or in specialized storage provided by gravel mass through which cooled night air is circulated.

The future development of new settlements in the arid zones really depends on the identification and exploitation of new economic opportunities. These may lie with tourism, as in, for instance, the rapid development of the Sahelian zone of Tunisia; the relocation of populations following the development of major irrigation schemes such as the Euphrates diversion or the Karakum Canal; the exploitation of fossil groundwater as at Tabuk, Tayma and Al-Ulla (western Arabian peninsula); or simply the deliberate redistribution of industry for strategic or social reasons. As yet very little integrated research is specifically addressed to the development of settlements in the arid zone. Individual aspects are being investigated but only one or two institutes have evolved an integrated approach.

MINING AND INDUSTRY

Where industrialization has taken place in the arid zones, it has almost invariably spread to coastal locations as, for instance, with oil and gas-based industries. The only significant exception has been the extraction of non-oil minerals where a large work force is required for the actual process of removing the substance from the ground.

There are still substantial reserves of minerals in the arid zones, e.g. phosphates in

northern Saudi Arabia and sulphur in Turkmenistan in the USSR, but their exploitation requires a very considerable investment in physical infrastructure such as roads, water, housing and power. Where the product is of sufficient economic value, as with the gold and silver of Koolgardie in Australia, water will be piped, in this case, over 500 km, to meet the needs of these settlements. Although it is often said that much of the water moved is used to create and sustain a life-style of baths, swimming pools and visual greenery, as at Arlit in northern Niger, instead of using it for productive agriculture, recent research appears to show the contrary. Dov Nir quotes the results of research in New Mexico:

> 0.9 per cent of the active population is occupied in agriculture; their share in the total income is 0.2 per cent and they use 17.9 per cent of the water; to attain 1 per cent of the total income, agriculture will have to use 88 per cent of the water. Industry on the other hand employs 21.6 per cent of the active population, who contribute 21.3 per cent of the total income, using for this purpose 0.2 per cent of the water. To produce 1 per cent of the total income, industry needs 0.5 per cent of the total water resources, that is to say, 178 times less than agriculture. (Nir 1974, p. 78).

Despite the lower unit cost of land outside urban areas and the cheaper labour usually found in the arid zones of developing countries, there remains the difficulty of finding non-mineral based industries which are specifically related to arid zone resources or where there is a willingness to move away from the well-established external economies of the coastal locations. Considerable scope remains for the growth of wool, hides and skins and for hair processing, but these activities require effective control over supply and quality which is not easy to achieve in a diffuse and mobile community situation such as that which prevails in areas of nomadism. In Soviet Central Asia and Mongolia, this goal has been achieved as part of major national programmes to integrate the nomads into a modern economy; agro-industrial complexes, especially for leather and textiles, have thus been established. Where major irrigation developments are envisaged, as in eastern Syria, a focus exists for processing and service industries related to the agricultural production and the new population. This mixed development will be worked into a general policy for water use in the new region. Although there will always be individuals willing, given the opportunity, to reverse the drift to the cities and escape the social costs of mass urbanization, it will almost certainly be necessary to offer substantial economic incentives to draw industries to these new locations.

Most governments are anxious to stimulate industrialization and hesitate to take any initiatives which would increase the costs and reduce the profitability of the enterprises concerned, though, again as in the case of Syria, the government may well be prepared to subsidize a move to the new locations to consolidate and broaden a development base. In any case, the basic infrastructure will have to be provided to cater for the agricultural production. Otherwise the infrastructural costs involved in relocation might well prove prohibitive. In any decision concerning the arid zones, governments must consider the opportunity cost of investing scarce capital; often this is stressed in terms of the expense of taking services to and transporting products from isolated, thinly populated areas. However, land is cheaper in the arid zones, which also in many ways provide healthier work environments.

Apart from the special case discussed above, it is difficult to envisage any major developments in the industrial sector of the arid zones in the foreseeable future. It does not seem likely that solar energy or wind power will be able to offer a major new resource, despite the present active research programme, until very substantial economic and storage problems are overcome. In the developed world, industries of a footloose nature have migrated to the arid zones, attracted by the climate and low land prices, but it is still expected that the normal full range of services will be provided. Those states which are fortunate enough to have considerable fossil energy reserves have already embarked on a two-pronged drive towards more diversified industrialization. On the one hand, the oil base is now being processed *in situ*, retaining more of the value-added benefits, and more by-products are being processed in the producer country (chemicals, gases, fertilizers, paints, etc.). On the other hand, more attention is being paid to innovative ways of using the energy base. With the dramatic rise in energy prices in 1973, the energy component assumed a new value in the economic cost/return equation. Thus, the possession of what is, in effect, 'cheap energy', is now a major location factor as it is no longer ubiquitous but very much country-specific. In Saudi Arabia, for instance, the night sky will no longer be illuminated with millions of cubic metres of flared-off gas (a form of waste which was used as a symbol by

some oil companies in the 1950's and 1960's), now processed for propane, butane and related products. Over $20 billion has been reserved for this purpose. Natural gas will also be used as Saudi Arabia's contribution to one of the largest steelworks in the world located at Jabayl on the Gulf, where Brazilian ore slurry is processed to make steel largely for Japan.

Where industrial development does take place in the arid zones, attention must be paid to its environmental impact in both the positive and negative sense and to linkages with other possible sectors of production. For instance, mineral extraction in arid zones in developed countries often involves the large-scale generation of power which might form the basis for a power-(water)-food complex on the Abu Dhabi model, especially as mineral workers often receive substantial salary supplements and are generally willing to pay high prices for fresh vegetables. If brackish or saline water is available locally, this activity can be integrated into the system. Again, water used in the production of power, in the mining process and in associated urban development is increasingly being recycled for agricultural purposes. Close attention must be paid, however, to the potentially considerable risk of pollution of the fragile desert ecosystem; very often pollution can be turned into production.

It is impossible to consider the question of industrialization in isolation; it is related, for instance, to the income derived from tourism which provides potential investment capital and to appropriate technology locally produced to overcome specific local problems. An example might be the village level production of agricultural devices to overcome identified labour bottlenecks in agriculture arising from intense seasonality of rainfall. The United Nations Industrial Development Organization (UNIDO) has evolved a Co-operative Programme of Action on Appropriate Industrial Technology which includes the promotion of technological research along two main lines: the adaptation of existing technologies and the development of new technologies to suit the conditions of the developing countries, especially using local resources. Clearly, an effort of this sort requires considerable interagency co-operation as the prospects for industrialization cross almost all sectoral boundaries. Initial attention of interest to the arid zones has centred on the extraction of oil from *Balanites aegyptiaca* trees and from the *jojoba* plant. Another part of the study concentrates on energy technology - solar, wind and biogas.

Finally, it is evident that some developed countries are exporting pollution to the arid zones. Anti-pollution legislation in developed countries is imposing costs which industrial plants can avoid by moving to locations where controls are less strict.

TOURISM AND RECREATION

In the arid zones of developed countries, the space, fresh air and spectacular scenery has become a major asset for the urban dweller anxious to escape the pressures of twentieth-century metropolitan life. Most of these areas have now been placed under some form of protection order thus conserving the resource base. The wilderness concept has now been extended further afield and tourists regularly visit central Tanzania, Mali and other parts of the Sahara. Coastal locations have been intensively exploited for those wishing to escape the European winter, so that the last twenty years have seen an explosive growth of areas such as the Baja California, Aqaba, Elat and the Club Méditerranée resorts in northern Africa. This form of coastal development is based almost entirely on the clear sea water and the long hours of sunshine. It is usually not of particular interest to tourists at these resorts that the 'development' they have inspired has changed the character of these locations totally, creating islands of the European life-style in the desert.

For the inland arid zones, however, the situation is different, as any change in the landscape, wildlife or traditional culture is likely to deter tourists. Yet all these aspects are under the most intense form of pressure, often accentuated by the presence of tourists and the tourist industry. It is doubtful whether large numbers of tourists would continue to go to Tanzania if, for instance, the game parks were poached out or required for settlement and if the Masai lived in neat houses and wove contemporary clothing. Tourist development must, therefore, be highly selective and will almost inevitably cater to small numbers of people in the upper income bracket. Consequently, investment *per capita* is high and, in the northern African context at least, could be considered as being complementary to the existing coastal development. At all times the fragility of the arid environment must be kept at the focus of planning, by attempting to 'come to terms' with the natural milieu rather than making it subservient to the European life-style. It is inevitable that much of what attracts tourists at present will disappear in the near future and that the emphasis will shift increasingly to space, sea, sun and sand.

Very little research has been carried out on the cost-benefit equation for tourism, which is generally assumed to be a major potential money spinner. However, to attract moneyed tourists from the developed world, poor countries have often made major investments in recreating some aspects of the European/American life-style: asphalt roads, international airports, luxury hotels with attendant staff, power, water and western food. In some countries it has been shown that in many years there is either a tiny real profit or a net outflow of funds. In making a cost-benefit study, it is necessary to consider tourism within the overall context of national economic development. For instance, new roads and water supply, as in Djerba, Tunisia, have a multiplier effect on the local economy, making the site more competitive and attractive for a wider range of economic activities than it was formerly. As far as possible, provision for the tourist is increasingly being envisaged at a modest level, whilst maintaining basic standards of hygiene, safety and comfort. The question might also be raised as to whether it is appropriate to expose the national population to a life-style which it has no hope of achieving; but this is a matter of national policy. Very serious questions need to be answered before large parts of the arid zones are turned into the playground of the rich. What is the real return from the tourist industry? What is the opportunity cost of local investment in infrastructure, water use? What are the social implications? Clearly, the emphasis should be on maximizing the benefits of tourism for the national economy and, as far as possible within this context, for the arid zones themselves. Tourism should, therefore, be planned together with cottage industries, agriculture, the preservation of local culture and its protection from corruption and rapid commercialization.

The major emphasis for tourism has been on attracting foreign tourists, but there is in several countries, e.g. Saudi Arabia, Egypt, Syria and India, a growing local tourist trade which could be threatened if the provisions are intended exclusively for those with a substantial capacity to pay. People in urban areas or humid coastal plains may be just as anxious to 'get away from it all', but they may be excluded by the European/American level rates for accommodation and other facilities. Attention needs to be focused at this level on planning for tourism in the future if it is not to become an exploitative luxury. In some cases spontaneous recreational investment is taking place, as in Saudi Arabia where many people in Mecca and Jiddah have traditionally moved up the escarpment in the summer and pitched a tent. Now the move is towards the acquisition of sites for second homes and the construction of unsightly walled compounds. The very greenery which attracted people in the first instance to specific locations is being sacrificed in the face of sprawl. To check this, the Saudi government has acted to zone land, institute development control, enact conservation legislation and draw up master plans for some of the principal locations.

V. GAPS IN RESEARCH AND PERSPECTIVES FOR THE APPLICATION OF FUTURE RESEARCH AND TRAINING

From the general review provided in Parts I-IV, it is possible to discern two major sets of implications: those associated with the organization, structure and perspective of research relating to the arid zones; and those of a more specific nature relating to gaps in individual lines of research, development and training at the present time.

Although this Technical Note is concerned specifically with the arid zones, many of the priorities identified in this chapter (especially in the sections concerning organization and application of research and training) have a much wider application and some might justifiably also be included in a similar document on the humid tropics. However, in a review of this breadth and historical perspective, it seems most useful to present as comprehensive an analysis as possible.

It is very important to conduct at regular intervals a general evaluation of the total research effort and its relationship with planning and decision-making processes. Those involved directly in the daily business of research and its application frequently have too little time or information to see how their individual contribution relates to the wider picture and changes in this picture over time. They might also not be given the opportunity to see where their component effort fits in the overall planning process. The traditional isolation or withdrawal of the scientist or technologist from policy-making is breaking down, and the planning process is slowly moving into a wider conception of problems.

Along with this general point of view, there is a need for more detailed evaluations of research trends in each of the sectors identified in Part IV. These evaluations would put the experience of the last generation under scrutiny and draw out the lessons to be learned, and at least partially offset the disturbing tendency for the same mistakes to be made over space and time. It is, in fact, quite remarkable, in view of the scale of investment, the number of people involved and the low rate of success in applying technology in the arid zones, that such evaluative studies have so rarely been carried out.

Thus it would be valuable for a series of in-depth evaluations by specialists in each of the sectors identified in Part IV to be made of the experience of research and the application of research to the arid zones. This effort should include the role of the social sciences. This could possibly be built into the recent initiative of the United Nations University to assess the application of knowledge to arid zone problems.

ORGANIZATION OF RESEARCH

The time has come to compare and evaluate the efforts of some of the older established research centres and some of the innovative organizational structures devised by different governments for the application of knowledge and the planning of the arid zones.

An evaluative procedure should, henceforward, be built into the new centres being developed so that there is a really critical assessment of how well they are dealing with the problems of the arid zone, of which techniques and organizational structures have been most successful, etc. Evaluation is an essential feedback into the research programme. For this to be effective, clear universal guidelines need to be set out and widely applied; otherwise what will result will be a measure of 'efficiency' in applying the terms of reference of the organization. These themselves may prove inadequate over time and may be the weakness constraining

the effort. In addition, the professional constraints on academic researchers need to be studied, for what they do is often more related to the requirements for professional advancement than the tackling of high priority problems. For example, in many Latin American countries it is a requirement that researchers publish a minimum number of papers abroad, in a foreign language. Related to this problem is the issue of funding, which really determines what research is done.

The one clear and continuing demand is for integration across all sectors to keep a problem orientation as the focal point. It has been shown that, on paper at least, this is increasingly the case for research into primary production; for industrialization, urbanization and tourism, it is much less so. Gaps still exist at the funding level for research in many countries where the natural sciences and social sciences are rigidly separated. Care is needed to see that institutional policies and organization are really reflected in the work carried out. It is necessary to emphasize that the cries for systems approaches and integration do not diminish the need for continuing technical research of a high order. The particular need is for deficient areas of research (socio-economic) to 'catch up', for a more appropriate framework for research, and for more appropriate application of research results.

Every effort must be made to strengthen the local capacity for research at an appropriate level. The focus for this effort is, and probably will remain, the national level, for that is where policies are formulated and where decisions are ultimately made. A major effort will be needed to train future trainers and thereby to ensure a continuing capacity at the national level. As far as possible, the emphasis in training should be shifted to the countries concerned where skills and concepts can be acquired and tested *in situ* through, for instance, more emphasis on counterpart training as an integral part of most research work. The perspective must be turned away from a continual focus on the developed world. It is true that developing countries will never have the Research and Development (R&D) capacity of some of the rich countries, but they can build up their own skills in evolving technologies suitable for their own national circumstances. In addition, such people could assess the value of alien technologies in their own social and physical context and resist the cries from many rich countries that 'we have already solved your problems'. A plea is not being made for each country to rediscover the wheel, but for the strengthening of their capacity to assess their own, peculiar problems in a way appropriate to their own peculiar circumstances. It has recently become a disturbing reality that many countries identify their problems in terms of what they feel the agencies will fund.

Substantial research at the present time is concentrating on modelling exercises. Here a cautionary note needs to be introduced, for, although quantitative systems modelling offers a significant methodology for mathematically replicating the production environment, there is a danger. The model can either reproduce a particular local production system incorporating all factors, or, on a general basis, represent a technical optimum within given socio-economic conditions. The physical variables are those most easily incorporated into a model. There is a danger that models worked out in one area may be transferred, like the technology of the 1960's, to another without local testing. The model represents the basis for future systems research, but it must be seen to be location-specific in physical and social terms. Although superficially it may appear simple, without first creating precisely similar conditions, than it was with other aspects of technological development, it will be no easier to transfer a model from, for example, Australia to Niger. Models may, however, be tested for appropriateness and the model-building approach is universal.

It might be constructive for individual countries to draw up guidelines or principles for the conduct of further research and its application. These guidelines must be sufficiently flexible to accommodate the pressures and pace of change in many countries.

The research effort at the national level should not consider the arid zones in isolation any more than individual components of the production system should be considered *in vacuo*. It will be necessary to consider the relationship of these zones to the national development effort in order to absorb surplus population, ensure a fair price for commodities from the arid zones, etc.

APPLICATION OF RESEARCH

Since so many countries now operate within the context of a national (and/or regional) planning system, it is necessary for the research effort to be formally incorporated within this system, in order to ensure that the research is related to some specific objectives and tied in with the national policy structure. The development plans would then also consider the

institutions and institutional linkages appropriate to the needs of integrating research, applying research to specific priority problems and bringing together the research and decision-making processes. At the present time, research is not an explicit feature of many development plans, and thus a major part of the planning process is excluded from questions of policy.

It is necessary, on a broader scale, to rethink and strengthen the links between the research effort, the researcher, policy decision-making and implementation. This is by no means a problem specific to arid zones. Far too often research takes place in a policy vacuum and consequently yields a high proportion of results which cannot be implemented. Researchers are accused of 'ivory-towerism' and the administration of being 'bureaucratic and obstructive'. A realistic solution will only be found when a workable structure is created which brings both parties together, such as, perhaps, in a National Council for Science Policy and Development. Even then, this solution will work only if people are prepared to recognize the problem and have the will to face up to it. Pure science and political expediency are two ends of a scale, and each party tends to assign members of the other to the far end of the scale. As long as one group is charged with pushing back the frontiers of knowledge and the other with providing the fruits of this labour to the population, it is only common sense that the closest possible working relationship should exist between them. Where foreign researchers are admitted, the research proposals should be of immediate relevance to the countries concerned and the findings must be left in the country of study.

Much more effort is needed to restructure the level of decision-making to reflect advances in research organization. This is a political decision, but it is necessary to be more forthright in pointing out the barrier which the rigid, sectoral division of administration represents to any advance in treating problems involving ecosystems. International agencies, too, need to concentrate on joint efforts. Although liaison does take place, it could be strengthened, perhaps by a permanent interagency arid zone commission. The skills and experience for such a body already exist throughout the agencies as well as both national and international research organizations. What is needed is a structure to bring these institutions together effectively in order to reinforce national and international efforts in the arid zones. At the national level, thought should be given to effective decision-making structures, possibly through the mechanism of regional planning to pull ideas together and, in some cases, to give the arid zones their fair share of attention rather than their continuing to be the poor relations of the more humid areas of individual countries. Saudi Arabia, for instance, is preparing integrated regional plans appropriate to each of its many and diverse physical/socio-economic zones.

In many cases governments should seriously consider drawing up national resource policies and associated legislation, especially for water, within which to enact research and development. As long ago as 1961, the World Bank wrote:

> ... we strongly recommend the preparation and the implementation of a practical and effective national water code which would regulate the control, the development and use of water resources throughout the state. This code should establish the principles on which water should be developed and used, and should provide ample means of supervising and enforcing strict adherence to this code by everyone.

It would, for instance, have been difficult to envisage the success of Iran's national water development without such a policy. It must be stressed, however, that

> no simplistic or incomplete approach can be taken to the formulation of sound water policy ... Water policy based upon an efficiency approach is possible in the physical and economic realms. Probably the most important variable contributing to the success of any water policy is the characterization of social well-being; yet this is precisely the variable that appears to be the least understood ... (This) consideration should receive the highest priority in the formulation of policy (Dove 1977).

TRAINING[1]

Although it will always be necessary to train specialists, and integration is no alternative to this basic requirement, it would be valuable to add some perspective to the training of specialists so that they appreciate the need for integration as well as their role in the planning process; where their particular skill fits in the overall picture; the priorities for research in the production system of the local

1. See also preceding section on organization of research.

situation; and the likely repercussion of the application of their research in the local circumstances. Training has a further important function in many countries where the application of science and technology is limited by the numbers and skills of trained personnel.

RECOMMENDATIONS CONCERNING GAPS IN RESEARCH

Whatever the mistakes or inadequacies of research in the arid zones in the past, and whatever the frustrations felt about research at present (especially on the part of politicians), it must be recognized that basic scientific knowledge of arid zone resources is seriously deficient. It is essential that scientific work continue and be adequately supported in terms of funding and training. However, this work needs to fit into some policy framework. No amount of integration will ever replace the need for specialist research by specialist workers: the framework and the skills should be developed together.

Rainfed agriculture

Climate and climatic change

Semi-arid areas are characterized by steep rainfall gradients. In the Sahel, for example, there is a 1.4 mm decrease in precipitation/km in a northward direction. In the semi-arid Beer Sheva region rainfall decreases southward by 6 mm/km. Even slight changes in the local or global circulation can cause drastic changes in the amount of precipitation in these marginal areas. It is imperative that a greater knowledge of the factors affecting these circulations be obtained and that their influence on both short- and long-term climatic changes be accurately assessed.

In the climatic and meteorological fields, gaps in research emerge in the following areas: assessment of the problems of existing data collection, distribution and use systems; relationship between climate and the desertification process; problems of the general circulation over the dryland areas of the subtropics; climatology and bioclimatology of the dryland surfaces and closer integration of climatology with geomorphology, soil science, hydrology and ecology in these areas. This level of interaction should be reflected in an awareness on the part of atmospheric scientists of the various economic, social and political issues that climatic instability accentuates. It would be instructive to obtain a greater understanding of the positive feedback cycles exacerbating desertification. The subjects requiring elucidation include the climatic influences of increased albedo and dust and the lack of condensation nuclei due to destruction of vegetation.

Ecology of semi-arid regions

Insufficient baseline data is available for arid and semi-arid ecosystems. Even less is known of the reaction of these ecosystems to change as a result of human intervention. More data is needed on: environmental reaction to irrigation projects (spread of insect, plant and animal pathogens, soil fertility, microclimatic changes, etc.); ecosystem reaction to revegetation with annual or perennial grasses and legumes; effects of reforestation with fodder bushes or trees; interreactions of natural vegetation and newly-developed rainfed or irrigated crops; changes in soil fertility due to changes in grazing patterns or in animal/area ratios.

The availability of this type of scientific information would enable developers to take precautionary measures to ensure minimal environmental damage, while at the same time obtaining optimal exploitation of natural and developed ecosystems.

Conservation and use of soil moisture

Arid and semi-arid zone rainfall is characterized by its seasonal concentration and by its relatively high intensity causing loss of water due to runoff. The hot and dry rainless season results in the total loss of soil moisture by evaporation from both soils and plants.

Runoff from cultivated areas can be prevented by proper tillage and by maintaining good soil structure. However, there are no economically feasible means to increase soil permeability on the large areas of natural range which comprise the majority of arid regions. This could possibly be accomplished by change of vegetative type, terracing, or by chemical or organic soil amendments. Unfortunately, knowledge is extremely limited and large quantities of rainwater are lost, taking with them a yearly toll of the more fertile top soil.

The water which does enter the soil is subject to rapid evaporation, both in cultivated land and in rangeland. More information is needed on the possible use of soil conditioners to prevent or reduce this evaporation. New and cheaper mulching materials are required. In Israel, for example, yields of unirrigated tomatoes have been increased by over 50 per cent by use of plastic mulches, and, even in a relatively dry year, economic yields are often obtained. Techniques for prevention of evaporation from soils are still relatively primitive.

Research on the use of anti-transpirants has not as yet produced economically applicable results. The development of a cheap chemical spray which could effectively reduce transpiration without impairing CO_2 uptake could be of paramount importance.

Physiology of plants

Little is known about the physiological mechanism by which plants react to heat, salinity and drought. Such knowledge could possibly enable the development of suitable agrotechniques for combatting these conditions of environmental stress, and aid plant breeders by providing physiological parameters for selection and breeding.

There are even greater gaps in knowledge of the physiological and biochemical mechanisms of desert plants. Some desert species (e.g. *jojoba*, acacias, *guayule*, etc.) could be of significant economic importance. Almost nothing is known about their mechanisms of regulation of water balance, dormancy, flowering, fruit set, or of the biosynthesis of oils, waxes, gums and other materials produced by many desert plants. Better knowledge of these mechanisms could be of considerable economic importance.

Conservation of soil and soil fertility

Despite the vast scope of investigation on desert soils, basic techniques for soil conservation are still lacking. The interactions of the various crop rotations with tillage methods, stubble mulching, etc., have only been superficially investigated. Efficacy of soil amendments under various conditions of precipitation are mostly unknown. This type of information is needed for a wide range of rainfall, soil and crop conditions.

There are no clear criteria for determining the limits of climatic and soil conditions where rainfed agriculture can be expected to produce crops without causing serious or permanent damage to the soil. The development of soil-stabilizing materials or fixation agents for physico-chemical protection of soils would be of great benefit. Some suggested materials have been clays, rubbers, polymers, etc.

Plant introduction and propagation

Attention should be focussed on assessing the value of the physical and organic resources indigenous to the arid zones as a potential resource base for future development. Although much work has been carried out in the area of mineral exploration and evaluation, much remains to be done on the assessment of genetic material and the economic potential of many plants and animals. In particular, it should be remembered that indigenous plants and animals may perform better outside their area of evolution. Surprisingly little attention has been devoted to the cross-zone identification and selection of plants and animals. All this requires intensive study for propagation and selection.

The methodologies available for selection of exotic species for introduction into arid and semi-arid regions and the techniques of introduction themselves require clarification and adaptation to the specific conditions of each region. Where potentially valuable species have been identified, relatively little organized systematic effort has been made to examine the possibility of utilizing them in foreign desert regions. The huge potential of these plants has gone largely unexplored.

The genetic improvement of perennial woody species is a long and tedious process. If suitable methods of vegetative propagation were available for large-scale reproduction of superior individual plants within a species, yields could be increased several fold. This has been noted with *jojoba* bushes where the best individuals yield at least five times average yields. The same is true for most wild species. Economically viable techniques for mass vegetative propagation are not as yet available for most woody species. The new tissue culture propagation technique holds promise for overcoming this problem.

In temperate regions and in irrigated areas, introduction of new species and varieties has been of incalculable value to conventional agriculture. In arid and semi-arid areas, however, satisfactory methodologies for species selection and for adaptation and introduction of exotic plants have not as yet been developed. Little has been done to gain experience in the use of indigenous arid zone species of potential value. Successful introduction requires basic knowledge of soils and climate of areas of plant source and of the target areas. It would be of great value to have these data available when considering possible introductions as well as growing habits and physiology of the candidate species. For example, *guayule* requires a long period of water stress which seems to be a determining factor for initiating rubber biosynthesis. Caution would be necessary before *guayule* plantations could be recommended for regions lacking a long hot summer. It has been suggested that data be amassed on climatically analogous areas, but this should not be the sole criterion for selection of plants for introduction to new regions.

Industrial crops

The use of arid zone industrial plant species as a source of renewable raw materials in these areas has been receiving increasing attention. Some new species are presently entering the stage of commercial exploitation. These would include *guayule* rubber production in Mexico and production of *jojoba* oil and wax in the United States, Israel and Mexico. Other conventionally utilized industrial species, such as arabic gum, etc., are still high export earners for several countries, including Sudan and India. Many industrial species could have multiple functions. For example, *jojoba* could serve as emergency fodder during a drought year. *Guayule*, in addition to supplying natural rubber, could also be a source of resin and the waste cellulose could serve as pulp or as much needed fuel. Research needs to be centred on selection of species and ecotypes, introduction into new areas, propagation of high-yielding ecotypes, agrotechnical systems, extraction methods and end product development. In addition, basic problems relating to biosynthesis of the desired material, hormonal regulation, water balance, etc., should be investigated. Technological surveys are needed to forecast future market demands and to evaluate possible competition from synthetic substitutes.

Forestry

Bearing in mind the multiple functions of woody vegetation and the very rapid rate at which supplies are being depleted, urgent attention needs to be given to incorporating woody vegetation forms into new or modified land use systems. The propagation of woody vegetation remains a problem receiving too little attention in the arid zones. There is a need for the selection of superior ecotypes of suitable species. Forest management for arid and semi-arid regions is insufficiently understood.

Agrotechnology

There are huge gaps in knowledge of suitable cultivation techniques for rainfed agriculture in arid and semi-arid areas. About two-thirds of the population in these areas are involved in agriculture, and various development programmes, such as those of USAID, are directed towards enabling them to achieve self-sufficiency for staple foods. This goal will certainly require far more knowledge and understanding than is presently available.

Work should be undertaken on the implications of 'averaging' versus 'maximizing' strategies in the arid zones. Many of the older systems of production concentrate on minimizing losses in times of hardship. To achieve maximum output it is necessary to plan the cropping pattern to make the best use of the best conditions. To do this, it is necessary to have some concept and system of storage either of the food itself or of the profits of its sale which may then be converted into food supplied through the marketing system. This procedure introduces a dependency situation for the producer, and the market/storage/transport infrastructure must be at least equal to the survival value of the existing traditional system. The costs, benefits and logistics of these alternatives need to be studied and thoroughly analysed.

Strategies of integration of rainfed agriculture with livestock management are either undeveloped or untested. The zonal limits to effective and economic fertilizer application are unknown. In Israel it has been shown that below 230 mm of winter rainfall, nitrogen application will not pay for itself. Water harvesting methods, which hold promise for many areas, have the drawback of inordinate labour requirements for repair of erosion damage. Greater research efforts must be devoted to the hydrological regime of each area in order to find methods for prevention of flood damage to channels and earthworks. Physical-chemical soil stabilization should be among the methods tried. Experimental work has been initiated for the incorporation of legumes into rotation systems in an attempt to develop multiple use-sustained yield strategies. The critical factors determining these strategies are still not fully understood.

Social, political and cultural factors

It is clear that these factors, more than any others, will determine the possibility of utilizing presently available technologies and those still to be developed. Information which could be vital for successful application of dry farming technologies is not usually available. This information should be obtained as soon as possible.

It is possible to test various schemes of social organization, on a limited scale, and to evaluate them for more widespread use. Such experimentation could include establishment of marketing and producers' co-operatives, subsidizing of various crops or practices, establishment of central storage facilities and so forth. Experiments of this type have been carried out in the dry areas of northeastern Brazil. Limited experiments applying soil bank concepts, use of zoning limits, purchase and retirement of marginal areas, etc., would give

valuable information on the applicability of such methods. Suitable incentives must be found to obtain the full participation and co-operation of the population involved.

Irrigated agriculture

The availability of water in an arid or semi-arid region can be of immense benefit to the area by increasing fertility and productivity, but it can also, on the other hand, be a major factor in the degradation of the land and deterioration of the health of its population. Much can be learned concerning these processes from the older established irrigation systems as well as from those recently constructed. Since water, as an instrument for development, is of such critical importance, it should be considered one of the highest priorities for further research. Both the information and the methodologies needed for effective water resources planning are largely inadequate.

Groundwater

There has been a considerable number of optimistic reports indicating the availability of both fossil and replenishable water under many arid and semi-arid regions. For example, the French *Bureau de recherches géologiques et minières* (BRGM 1977) has reported the existence in the Sahel of a rechargeable quantity of good quality water amounting to 60 billion m^3/yr at a depth of less than 100 m. These reports should be verified and more information concerning aquifer characteristics obtained. Groundwater exploration is vitally needed for development planners.

Considerable work needs to be done in assessing water availability and water use. The concept of aquifer management should be at the root of thinking in relation to groundwater, and it is on groundwater that the effort should concentrate as problems are far fewer where water is stored this way. Thorough assessments are needed to provide realistic figures of the rate of recharge, for even where the reserves are not fossil, the nature of the aquifer may be such that it does not permit the rapid movement of water to make up losses around the point of extraction.

Water transport and storage

About 50 per cent of irrigation water is lost by evaporation and seepage before reaching the field. Moreover, seepage losses contribute to problems of waterlogging and salinity. At present, lining of canals in undeveloped areas is prohibitively expensive. The use of plastic films for this purpose has reduced initial investment costs in many cases but maintenance and replacement costs remain relatively high. Of greater impact would be the development of local materials and methods to achieve an impermeable layer as an effective barrier to seepage.

Underground water storage has many advantages. However, suitable aquifers are not often available so that surface structures are needed. Open bodies of water suffer severe water losses by evaporation and seepage. It has been estimated that evaporation losses in the western United States amount to about 20 billion m^3/yr. Lake Nasser loses some 10-15 billion m^3/yr - over 15 per cent of the total used. Often the quantity of water evaporated from an artificial lake is far greater than the amount used for irrigation. In addition, open water surfaces are notorious for the growth of disease-spreading organisms such as snails, which act as hosts for the debilitating schistosomiasis parasite.

There is a need to revive research on methods of evaporation prevention and seepage control. Alternatives to large open surface storage lakes and ponds must be sought. Often simple management techniques such as immediate use of water captured from flash floods can reduce water losses.

Irrigation technology

The correct use of irrigation technology can bring immense benefit to arid areas where water is available. For example, during a ten-year period, agricultural yields in Israel were almost doubled even though little additional water was supplied. Considerable research was needed to attain this accomplishment. For most arid zone developing nations there are insufficient agro-meteorological data for determination of plant-water requirements. The plant-water relations of the important local crops and indigenous plants of potential value are largely unexplored. Soil-water characteristics so important for designing adequate drainage systems are lacking.

Simpler and more inexpensive irrigation and drainage systems are needed, as well as cheap mulching materials for conserving soil moisture. Appropriate techniques requiring less capital investment must be found for use in newly developed areas.

Saline water could be used effectively with adequate drainage. The use of soil amendments to improve the physico-chemical soil properties and hence extend the range of saline irrigated crops, has not been sufficiently investigated. Better soil properties could also reduce the cost of drainage. Genetic amelioration of plant

resistance to salinity would have similar advantages. A better understanding of the physiological response of plants and the physicochemical reaction of soils to salinity would be of great value for the efficient and non-destructive use of saline waters.

Non-conventional water sources

Increasing energy costs have reduced the feasibility of using desalinated ocean water for irrigation purposes. However, where sufficient capital is available, water desalination is often the most practical alternative for supplying water to growing urban and industrial centres. The development of solar or wind energy for this purpose could possibly extend the use of desalination methods for other uses as well. Geothermal energy, which seems to be more generally available than previously thought, could become an important energy resource for water desalination utilizing lower temperatures than are necessary for economic electric power generation. As cities and industries grow in size and demand greater water supplies, the need for water recycling will increase. The recycling of municipal and industrial waste effluents could extend the available water supply. Cheaper recycling methods need to be developed as well as safeguards against health and environmental hazards. These effluents often contain valuable nutrients that could be utilized for cultivation of high protein algae, animal feeds or fertilizers.

Experimental recycling of agricultural water, a seemingly futuristic concept, has already begun in Arizona, Abu Dhabi and Saudi Arabia. This concept is both capital and energy intensive but could have important applications. There is a need to develop cheaper plastic structures and efficient cooling schemes for prevention of heating or removal of accumulated heat. Methods of increasing plant resistance to heat, as for example the addition of CO_2, should be investigated.

More basic information is needed in the field of cloud physics and mechanisms of rain formation. Such information could be the basis for future schemes for weather modification, including rainfall enhancement.

The idea of transporting water in large plastic balloons or in the form of icebergs from Antarctica requires further technical and economic feasibility studies.

Social, political and cultural factors related to water use

Suitable legislation concerning the ownership and use of water resources should be enacted and adapted to the socio-political nature of each society. A system of incentives on the level of the individual farmer designed to encourage the more efficient use of water is essential. Such incentives would include water pricing, subsidies, water quotas, grants and loans for purchase of improved irrigation equipment. Limited experiments manipulating these factors could supply essential experience and knowledge.

Livestock

Arid and semi-arid regions contain over half the world's cattle, more than one-third of its sheep and two-thirds of its goats. However, productivity is very low and the interaction of social, economic and climatic factors has periodically lead to catastrophic drought, famine and degradation of the regional productive capacity.

Survival and productive strategies

The survival and production strategies of herders and farmers need to be documented and quantified before change is introduced. In addition, attempts should be made to record the body of environmental knowledge held by these communities. In particular, immediate attention should be concentrated on quantifying the survival strategies of these communities. Without this basic information it is difficult to envisage how one might plan for their change or response to change. In this respect a dynamic approach to economic anthropology is essential as part of the planning process. As part of this approach, it is necessary to examine the links between two or more production systems (e.g. farming and herding) as they are often mutually dependent, and the range of development options may well include building on these complementarities, e.g. in the zone bordering the Cordillera of the Andes or linking fodder crops and livestock in northeastern Brazil.

Range productivity and regeneration

A better understanding of ecological factors affecting pastoral systems is essential for the development of suitable management and drought strategies. Methods of determining carrying capacity for areas with such wide variations in annual precipitation are still unreliable. The use of exclosures has often been shown to be successful for regeneration of overgrazed areas but these experiments have been executed only on a limited scale. Rehabilitation of desertified areas with fodder bushes and trees has shown great promise but requires larger scale experimentation. A combination of cactus with bushes of *Atriplex* or fodder tree species

such as *Prosopis* or *Acacia*, which are rich in protein, could provide a high-yielding and nutritious combination. Some initial work has been done on this in northeastern Brazil and the results appear to be promising. As mentioned in a previous section, selection and introduction of suitable exotic species holds great promise for such rehabilitation.

Recent work at the Soviet Institute of Deserts in Turkmenistan demonstrates the value of using biometeorological data for predicting pasture yields and for directing herds to regions of greater pasture availability.

Animal physiology

More data are needed concerning the adaptation of animals to the stressful environments of arid and semi-arid areas. A good deal of information has been obtained concerning physiological response to heat but few data are available to demonstrate the effect of heat and water balance on the production of meat and milk. Problems concerning nutrition, such as the effective use of supplements, efficacy of woody browse species, mineral requirements, etc., are still largely unsolved. Effective breeding for disease resistance and productivity under local conditions requires greater basic knowledge of the physiological parameters concerned.

The possibility of game ranching, using such animals as the gazelle, oryx, ostrich and others has been suggested. However, much more will have to be known about the physiology and behaviour of these wild species before reliable schemes for their utilization can be suggested.

Social, political and cultural factors related to livestock

An understanding of these factors is of paramount importance if range productivity is to be improved. For example, incentives to stimulate the sale of younger animals could in themselves provoke a marked increase in productivity and could possibly be accomplished by subsidizing prices for young animals. Co-operative ranching and marketing schemes should be tried where suitable, as well as other forms of social and organizational structures. A comprehensive set of incentives adapted to local conditions is lacking and is of vital urgency.

Settlement and urban development

Population dynamics

The size, dynamics, distribution, evolution and rates and reasons for migration are all still very largely unknown in many parts of the arid zones. Such data are fundamental for any planning exercise. In some parts of the arid zones, more is known about the minerals than the people. At the root of the ecological problem is often overpopulation with respect to resources and technology. It is impossible to adhere to any critical population density or carrying capacity concept if there are no reliable data on human populations. Also, without any measure of growth, there is no conception of the scope and size of the problems likely to arise in the future. This is not just a question of data collection, for there is some evidence that the population dynamics of nomadic peoples are different from those of their settled neighbours and that, if settled, the nomads will show an increase in the rate of population growth.

Resettlement

Where overpopulation has strained physical resources, it may be necessary to relocate part of the inhabitants in areas with greater or unexploited resources. Some such attempts have been made, for example, in Peru and Brazil with the translocation of population from the arid areas to the more humid tropics. It would be important to obtain more information on the successes and failures of these attempts.

Further information on resettlement could be obtained by tracing the fate of peoples displaced by large water development projects such as that which occurred in Lake Nasser and Lake Volta. Limited experimentation with various incentives to encourage relocation and various means of social and economic co-operative settlement organization is necessary.

Building and architecture

More suitable and climatically acceptable dwellings and workplaces have to be designed. Insufficient resources have been allocated to the improvement of local building materials. For a discussion of recent research on the effect of building design and materials on the indoor climate and the energy needed to provide comfortable conditions, see Part IV.

Health

A physically debilitated population can do little to improve its lot. Desert people suffer greatly from zoonotic diseases because of their close contact with animals. Often development projects bringing water to previously dry areas bring in their wake a new set of disease factors Lake Nasser, Lake Volta and the Gezira project in Sudan are good examples *inter alia* of the possible harmful consequences of water resource

development. Better techniques are needed to avoid these pitfalls and to remedy them when they do occur.

Energy

For some two-thirds of the inhabitants of arid and semi-arid regions, wood is the source of energy available for home use and for small industrial enterprises such as ceramics, brick-making, curing and smoking of fish and tobacco, etc. The gathering of wood has been a major cause of widespread environmental destruction and often irreversible desertification. Recent estimates suggest that 2 million hectares of woody steppes are devegetated each year and the zone of stripping often extends for 50 km around settlements. Fuel bills form one-third of family expenditure in parts of Yemen and in Sahelian countries. In southern Asia dung is used as a domestic fuel depriving the lands of a valuable organic nutrient. Alternate energy sources are desperately needed.

Reforestation

Reforestation with fast growing species such as *Eucalyptus*, *Prosopis*, *Acacia*, etc., and the institution of suitable management techniques is probably the most rapid and economic means of supplying energy in a socially acceptable form. Such projects have the additional advantage of being ecologically sound, and if multi-purpose species are used, could also have additional economic utilization. Improved species, propagation methods and management techniques, together with suitable incentives, are urgently needed.

Alternate sources

Wind and solar energy research is still gathering momentum but will probably have little impact in arid areas in the near future. The use of biogas seems promising but still needs simpler and cheaper apparatuses. Geothermal energy seems to be more generally available than previously thought and research in this field should be given a higher priority. New techniques of obtaining energy from salt now being investigated in Japan, the United States and Israel should be encouraged.

Renewable resources

In addition to reforestation, investigation of energy-farm concepts should be explored. A good example of this idea is the use of specific desert plants, such as *Euphorbia* species which produce a hydrocarbon latex. Other desert plants could also be used if feasible techniques and species are developed.

Mining and industry

Industrial development is an excellent growth stimulant and where conditions are suitable, such activity is often the preferred alternative for development. Natural deposits of petroleum, minerals and salts, as well as agricultural products, are often available in desert regions and can form the resource base for mining and industry.

There are considerable gaps in our information concerning these resources and the technologies needed to exploit them under the constraints of the arid zones.

Minerals. Geological and mineral exploration have not been undertaken in sufficient detail, except in known petroleum-rich areas.

Water. 'Dry technologies' for mining and manufacture need to be developed. Recycling of industrial effluents could greatly reduce water requirements.

Energy. There is a need for industrial processes based upon low-grade energy sources such as those provided by solar or geothermal energy.

Political factors. Various incentives need to be tested for their efficacy in attracting capital and technology to these remote areas. In addition, major programmes for infrastructure development will be necessary.

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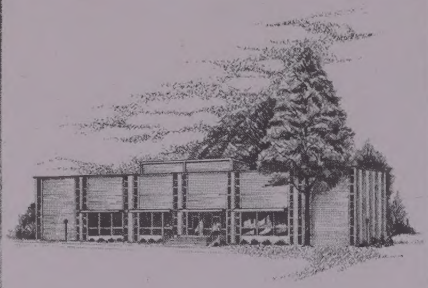

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During the last twenty-five years, impressive scientific and technical advances have been made in resource use and development in arid zones. But this knowledge has been difficult to apply in combating the complex problems of arid zone development as research has often been narrow in scope and has not given full consideration to social, economic and political factors.

Based on the work of a United Nations interagency task force, this Technical Note stresses the need for integrated research which takes into account all aspects of a given situation. The main sections deal with the resource base and its potential for the development of the arid and semi-arid zones; the general trends and major changes in the nature and organization of research and its application during the period 1950–75; the trends and gaps in research by individual sectors of the economy, such as primary production, settlements and urban development, mining and industry, and tourism and recreation; and the planning implications arising from this study.

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A stylized "ankh", the ancient Egyptian sign for life, has been incorporated into the symbol of the Programme on Man and the Biosphere (MAB)

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